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ABSTRACT

This technical specialty course is one of thirty-five courses designed for use by two-year postsecondary institutions in five nuclear technician curriculum areas: (1) radiation protection technician, (2) nuclear instrumentation and control technician, (3) nuclear materials processing technician, (4) nuclear quality-assurance/quality-control technician, and (5) nuclear reactor (plant) operator trainee. This course, Instrumentation and Control of Reactors and Plant Systems, contains six modules: Neutron Monitoring Systems, Neutron Sensors, Neutron Flux Signal Conditioning, Control Rod Drives and Indicating Systems, Instrumentation Power Supplies, and Installation of Instrumentation Systems. Each module follows a typical format including the following sections: introduction, module prerequisites, objectives, subject matter, exercises, materials, procedures, data tables, reference materials, and tests. (A master index and suggested program planning guide are also available--see CE 026 856 and CE 026 639-643.) (LRA)

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ED192090

Nuclear Technology Series

COURSE 6
INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

TECHNICAL EDUCATION RESEARCH CENTER- SW

4201 LAKE SHORE DRIVE - SUITE 111

WACO, TEXAS 76710

JUN 1980

CE 026 648

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PREFACE

ABOUT NUCLEAR TECHNOLOGY MODULES

The modules - developed by TERC-SW for use in two-year postsecondary technical institutions to prepare technicians for employment - are useful in industry for updating employees in company-sponsored training, and as laboratory texts in engineering schools. The principles, techniques and skills taught in the modules, based on tasks that nuclear technicians perform, were obtained from a nationwide advisory committee of employers of nuclear technicians. Each module was written by a working technical expert and tested with students.

A module contains the following elements:

Introduction, which identifies the topic and often includes a rationale for studying the material.

Module Prerequisites, which identify the material a student should be familiar with before studying the module.

Objectives, which clearly identify what the student is expected to know for satisfactory module completion. The objectives, stated in terms of action-oriented behaviors, include such action words as operate, measure, calculate, identify and define, rather than words with many interpretations, such as know, understand, learn and appreciate.

Subject Matter, which presents the background theory and techniques supportive to the objectives of the module. Subject matter is written with the technical student in mind.

Exercises, which provide practical problems to which the student can apply this new knowledge.

Materials, which identify the equipment required to complete the laboratory procedure.

Procedures, which is the experiment section, or "hands-on" portion of the module (including step-by-step instruction) designed to reinforce student learning.

Data Tables, which are included in most modules for the first year (or basic) courses to help the student learn how to collect and organize data.

Reference Materials, which are included as suggestions for supplementary reading/viewing for the student.

Test, which measures the student's achievement of the prestated objectives.

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The Nuclear Technology Series will consist of five curricula when completed:

Nuclear Reactor (Plant) Operator Trainee.
Radiation Protection Technician.
Nuclear Materials Processing Technician.
Nuclear Quality-Assurance/Quality-Control Technician.
Nuclear Instrumentation and Control Technician.

The completed Nuclear Reactor (Plant) Operator Trainee curriculum consists of the following sixteen technical specialty courses made up of 114 instructional modules:

Radiation Physics.
Radiation Protection I.
Principles of Process Instrumentation.
Heat Transfer and Fluid Flow.
Introduction to Nuclear Systems.
Instrumentation and Control of Reactors and Plant Systems.
Reactor Operations.
Reactor Safety.
Reactor Auxiliary Systems.
Power Plant Systems.
Radiation Detection and Measurement.
Reactor Physics.
Power Plant Chemistry.
Introduction to Quality Assurance/Quality Control.
Metallurgy and Metals Properties.
Mechanical Component Characteristics and Specifications.

Availability: Instructional modules are available individually or by courses from:

Technical Education Research Center - Southwest
4201 Lake Shore Dr., Suite 111
Waco, Texas 76710
Telephone (817) 772-8756

Printed:

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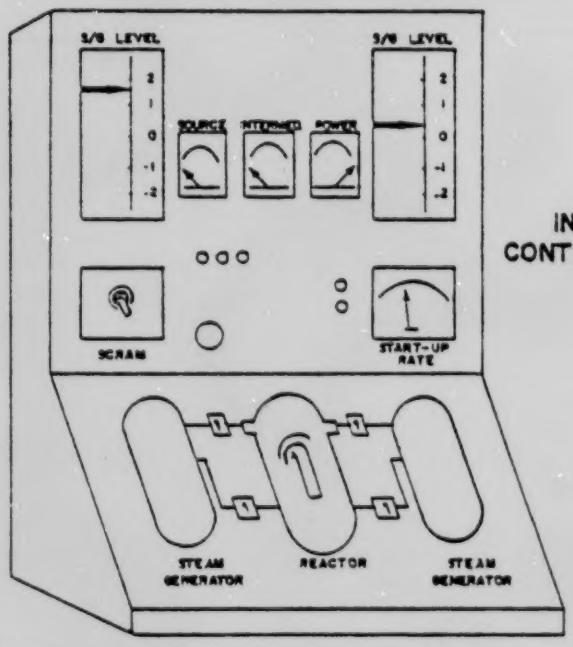
Module 6-6 Installation of Instrumentation Systems

NUCLEAR TECHNOLOGY

MODULE 6-1 NEUTRON MONITORING SYSTEMS, -

JOSEPH A. BURACK



INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

COURSE 6

TERC-SW

TECHNICAL EDUCATION RESEARCH CENTER — SOUTHWEST
4201 LAKE SHORE DRIVE WACO, TEXAS

COURSE 6 INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

MODULE 6-1 Neutron Monitoring Systems
MODULE 6-2 Neutron Sensors
MODULE 6-3 Neutron Flux Signal Conditioning
MODULE 6-4 Control-Rod Drives and Indicating Systems
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INTRODUCTION

The purpose of this module is to familiarize the student with the means by which nuclear reactor power level is measured, transmitted and displayed for the operator (Figure 6-1-1).

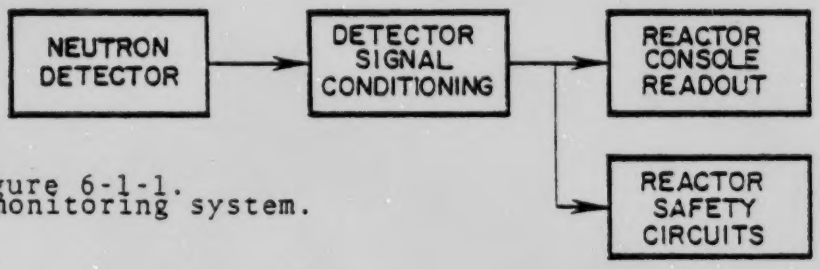


Figure 6-1-1.
Neutron monitoring system.

Methods of measuring the numbers of neutrons as a means of closely approximating the power level of a nuclear reactor form the content of this module.

MODULE PREREQUISITES

The student should have completed Course 5 of this series, and be especially familiar with such terms as neutron flux (n/cm^2-sec), effective multiplication factor (k_{eff}), decade, period, startup rate and reactor core.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Discuss why it is necessary to monitor neutron flux levels in a nuclear reactor, from source range through power range.
2. List and discuss necessary ranges of measurements, and overlap of these ranges of measurement.
3. Discuss interlocks and trips associated with ranges of measurement.
4. Discuss reasons for overlap of measurements.
5. Explain reactor power level, and neutron detection system range; use sketch to show overlap of systems.
6. Show that power level is proportional to neutron flux.
7. Describe source range, intermediate range and full-power instrumentation at a nuclear reactor.

NEUTRON MEASUREMENT

While neutron population is a valid quantity to equate with reactor power, there are other reasons for measuring neutrons. Over much of the range of reactor operation, little or no temperature change occurs; thus, measurement by thermal means is excluded. Also, whenever a mass of uranium is present, spontaneous fissions take place (one spontaneous fission every second per gram of uranium), providing a source of neutrons.

There are two basic methods of measuring the number of neutrons in a reactor core: first, neutron flux distribution in a reactor is not constant and may vary with time, position, control rod location, fuel loading and other variables. Because flux is not constant, it must be measured at various locations within the core. A large number of detectors placed uniformly throughout the core offer an average reading. One disadvantage of this method, used almost exclusively in BWR's, is that a large number of detectors are required and their lifespans are short. The main advantage of this system is that it does measure local neutron flux levels within the core.

This method has become more popular as reactors have become larger - detector placed on the outer surface of the core has difficulty "seeing into" the central region of the core. As many as 200 individual detectors may be situated in a typical BWR (Figure 6-1-2).

As the core ages, the vertical (axial) flux symmetry varies; therefore, it is necessary for in-core detectors to be movable in a vertical path to ensure accurate instrumentation (See

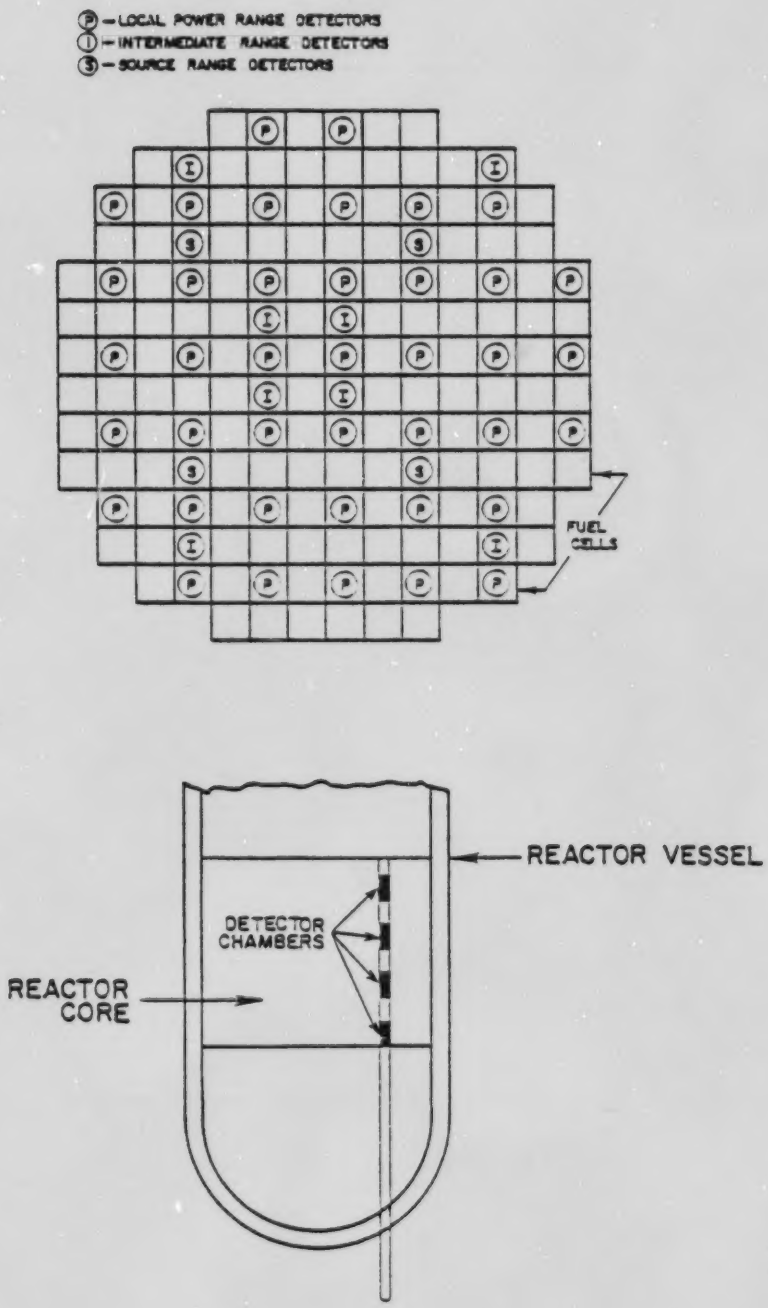


Figure 6-1-2. Typical placement of in-core neutron detectors.

Figure 6-1-3).

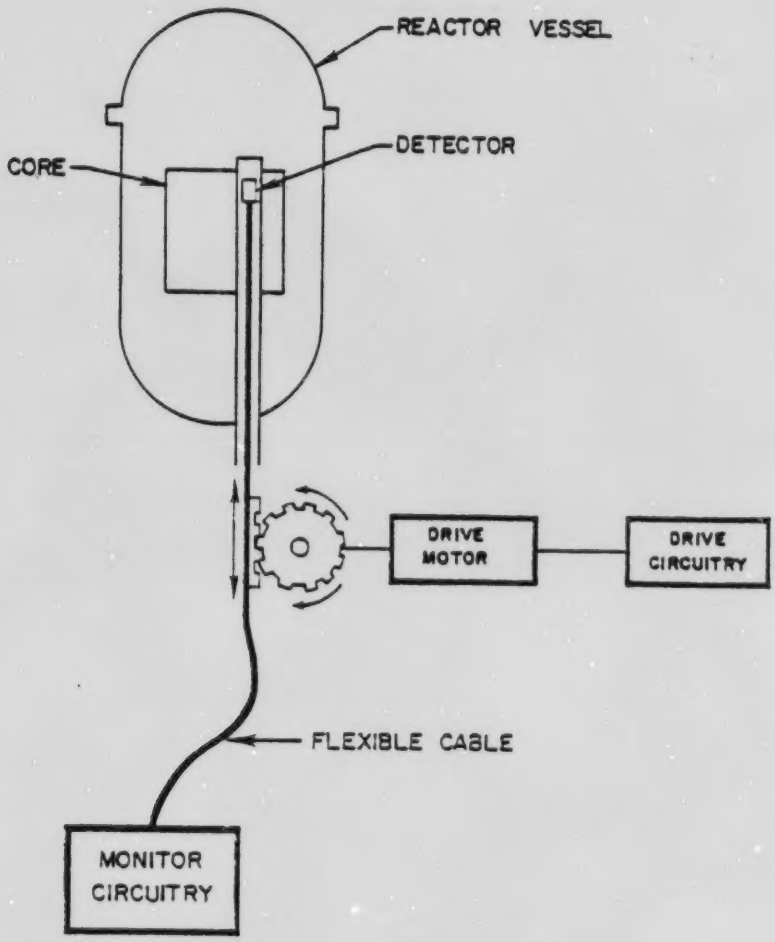
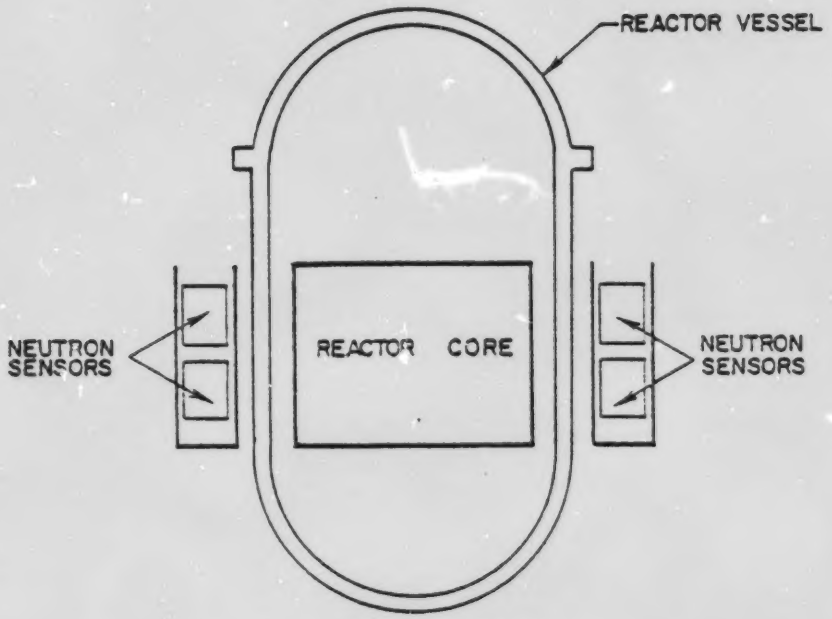


Figure 6-1-3. Position control system by which detectors are moved.

In a second approach, used in smaller power reactors and in research reactors, detectors are placed on the outside of the fuel region. They are far enough away from the core to allow the core to be considered a point source of neutrons (Figure 6-1-4). Local flux variations within the core are



Fire 6-1-4. Out-of-core detector locations.

less significant, and detectors only "see" an average neturon flux.

Both methods are in wide use and, in some cases, are even used together. Which method is prefered depends on what information is desired and how the reactor is built.

The power level of a nuclear reactor is assumed to be proportional to the number of neutrons in its core. In a reactor having a certain volume in cm^3, $VN\sigma_f\phi$ fissions per second occur. Because 3.1×10^{10} fissions/second are required to produce 1 watt of thermal power, the power P of a nuclear reactor can be stated:

$$P = \frac{V N \sigma_f \phi}{3.1 \times 10^{10}}$$

Equation 6-1-1
(Equation = Eq.)

where

P = power of reaction, in watts.
V = volume of reaction, cm^3.
N = $\frac{\text{number of fissionable nuclei}}{cm^3}$.
σ_f = fission cross section.
ϕ = neutron flux.

Because volume of the reactor, number of fissionable nuclei per cm^3, fission cross section and 3.1×10^{10} $\frac{\text{fissions/second}}{\text{watt}}$ are assumed to be constant, it can be seen that, if neutron flux (ϕ) increases or decreases, power (P) varies proportionately:

$$\uparrow P = \frac{\overrightarrow{V N \sigma_f} \uparrow \phi}{3.1 \times 10^{10}} \longrightarrow \qquad \downarrow P = \frac{\overrightarrow{V N \sigma_f} \phi \downarrow}{3.1 \times 10^{10}} \longrightarrow$$

Then, if ϕ increases by a factor of 10, P increases, by the same factor. Thus, a definite relationship can be seen between power level and neutron flux. Also, a great difference exists in neutron levels at 1 watt (compared with 10^9 watts). It is necessary, therefore, to monitor neutron levels for as much as a 10 decade range (from 10^{-1} watts to 10^9 watts) (See

Figure 6-1-5).

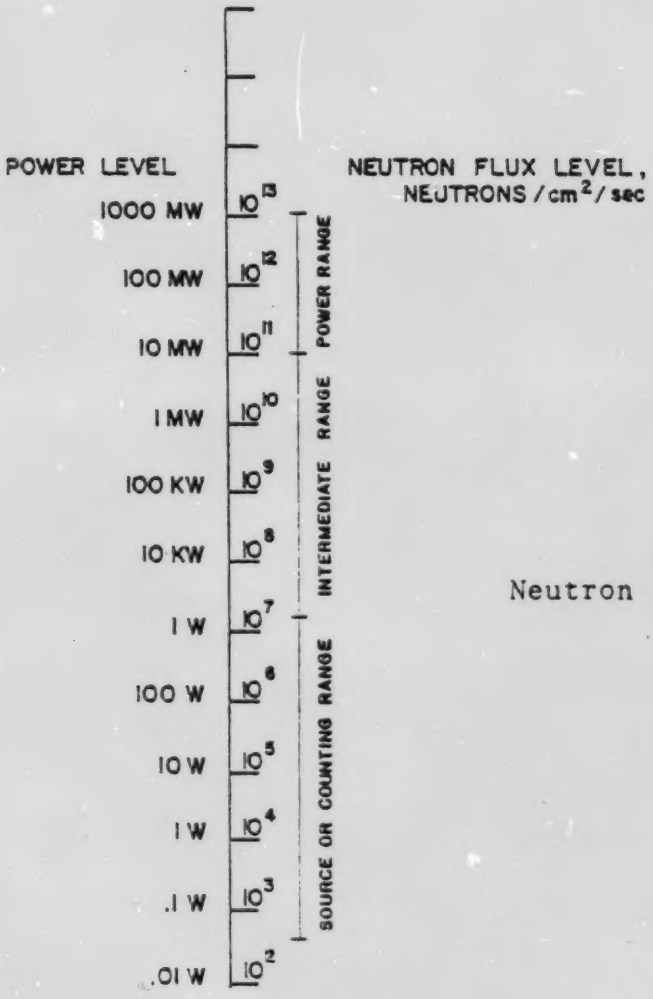


Figure 6-1-5.
Neutron level decade range.

Present day instruments are not capable of covering such a range; therefore, conventional full-range neutron detection utilizes multiple detector systems. These systems are designed to ensure that, prior to one detector being at its maximum readout, the next detector has begun to register. Because of this "overlap" between detector ranges, an accurate indication of neutron flux is always available to the operator (Figure 6-1-6).

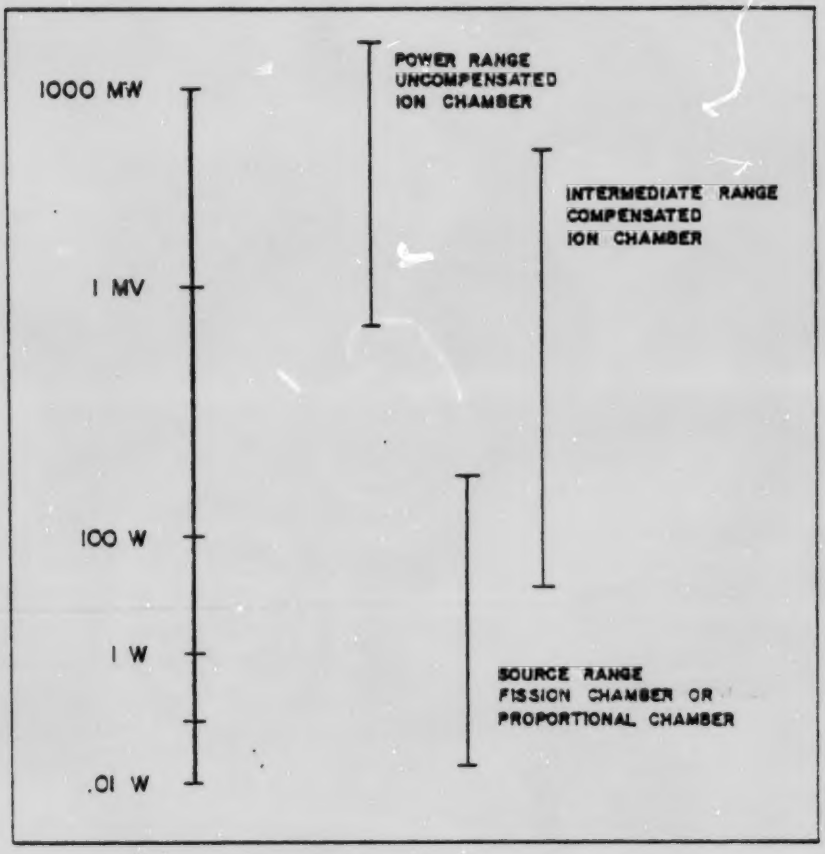


Figure 6-1-6. Multiple-range, multiple-detector system.

SOURCE RANGE

The lowest range (source range) covers from 4-6 decades of neutron flux. The lowest count rate depends on the strength of the neutron sources installed in the core and on core multiplication (associated with shutdown reactivity of a particular core).

In this range, the neutron level is between those points at which the reactor is 1) shut down as completely as possible

and is 2) just critical.

A minimum count rate interlock is usually incorporated into this circuit to prevent reactor startup if indicated neutron level is too low. This interlock ensures that a startup is not attempted with the neutron flux below the indicating range of the instrumentation, or with the instrumentation off, or otherwise inoperative. Startup is not necessarily dangerous because initial neutron level is low, but such a startup is risky because operator is unaware of what neutron level and reactor power are doing. The operator must constantly be aware of the status of the neutron level.

If any possibility exist for a multiplication factor greater than one, then a possibility exists that the reactor may attain a prompt supercritical condition. In such a case, tremendously high power levels may be achieved much faster than any present day detection system can detect (not to mention display and/or cause any of the numerous safety systems to operate).

In a basic source range instrumentation system (Figure 6-1-7), a signal from the detector is amplified to register on

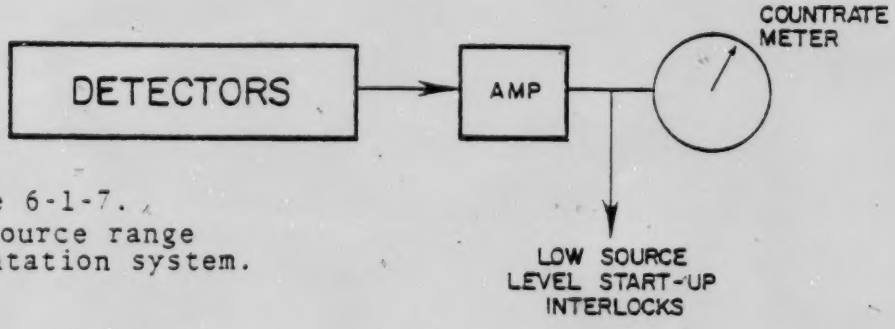


Figure 6-1-7.
Basic source range instrumentation system.

the source range meter in counts per minute.

INTERMEDIATE RANGE

The intermediate range covers approximately 4 decades. Neutron level, in this range, is between those points at which the reactor is 1) just critical and 2) slightly supercritical (at a certain period or startup rate) and beginning to generate thermal power. In this range, instrumentation is usually provided to generate both level and period information (rate of change of level). Period or startup rate trips are usually provided in this range of operation also (Figure 6-1-8).

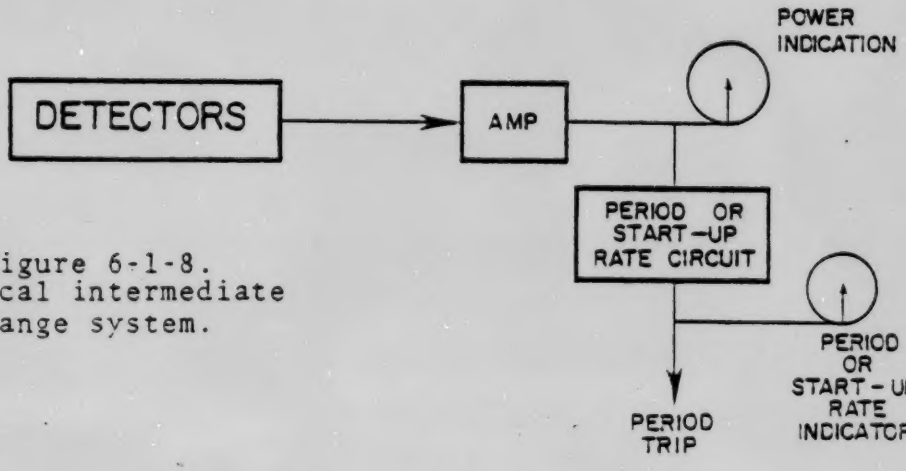


Figure 6-1-8.
Typical intermediate range system.

POWER RANGE

In power range the reactor is producing from 1 to 100% of its total rated output. This range usually covers 2 decades, but instrumentation may cover more to provide overpower protection, in the form of alarms or trips (scrams) (Figure 6-1-9).

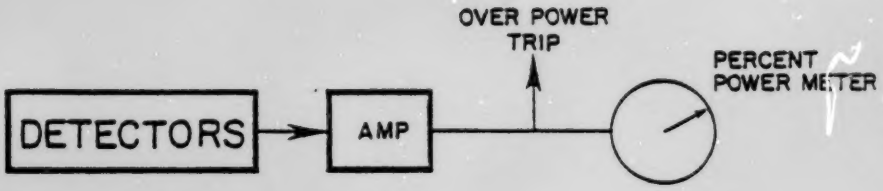


Figure 6-1-9. Typical power range system.

Instrumentation of a particular nuclear power plant may consist of four groups of source range detectors, four groups of intermediate detectors. Or, it may consist of up to 200 individual, movable or fixed detectors, or both. No matter how the system is arranged for a particular nuclear reactor, it must satisfy those basic requirements and practices outlined in this module.

EXERCISES

None.

MATERIALS

None.

PROCEDURES

If possible, tour a reactor control room and record the following parameters from control room instrumentation:

Linear power.
Percent power.
Intermediate power.
Control-rod positions.
Period.
Radiation levels.

DATA TABLE

None.

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1. Explain why it is necessary to monitor neutron flux level in a nuclear reactor, from source range through power range:

2. List and discuss ranges of neutron flux level measurement; include interlocks and trips (if any) associated with each:

3. Briefly explain reason(s) for overlap(s) between neutron detection systems:

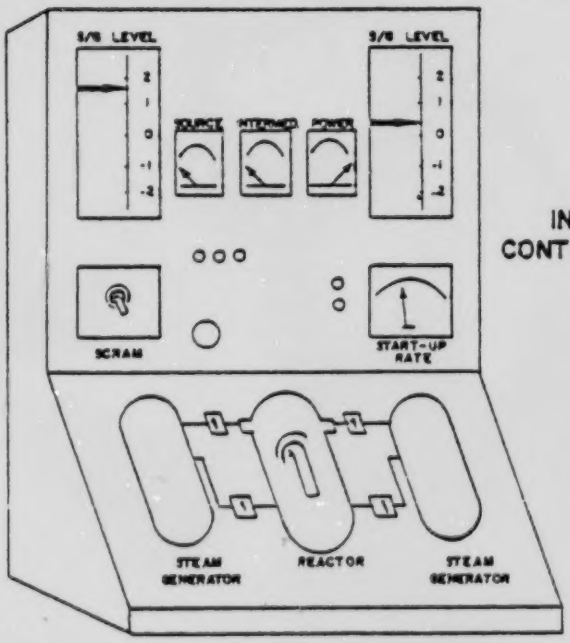
4. Sketch a full-range reactor power level and neutron detection system; show overlap(s):

5. Demonstrate that power level is proportional to neutron flux (use $P = \frac{VN\sigma_f\Phi}{3.1 \times 10^{10}}$ watts):

NUCLEAR TECHNOLOGY

MODULE 6-2 NEUTRON SENSORS, -

JOSEPH A BURACK



INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

COURSE 6

TERC-SW

TECHNICAL EDUCATION RESEARCH CENTER — SOUTHWEST
4201 LAKE SHORE DRIVE WACO, TEXAS

COURSE MODULES

COURSE 6 INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

MODULE 6-1 Neutron Monitoring Systems
MODULE 6-2 Neutron Sensors
MODULE 6-3 Neutron Flux Signal Conditioning
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INTRODUCTION

This module reviews the basics of gas-filled detectors, then examines the details of specific types of neutron detectors, emphasizing those most commonly used in nuclear power plants.

MODULE PREREQUISITES

The student should have completed Module 6-1, "Neutron Monitoring Systems."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List the most commonly used neutron detectors.
2. Sketch and explain the operation of each of the following:
   - Fission chamber.
   - BF_3 proportional counter.
   - Compensated ion chamber.
   - Uncompensated ion chamber.
   - Neutron thermopile.

3. State reasons for use and give range of each detector above.
4. Use a neutron source of known value (neutrons/seconds); calculate neutron flux at 1 meter and at 4 meters away from the source.
5. Use a BF_3 proportional counter to measure neutron flux.

GAS-FILLED DETECTORS

Gas-filled detectors are used in many ways in radioisotope analysis and radiation monitoring. Gas-filled detectors rely upon the ionizing ability of nuclear radiation. Alpha and beta particles ionize a gas directly. X-rays and gamma rays produce secondary particles that cause formation of ion pairs. Neutrons are neutral particles and cannot ionize a gas directly; however, neutrons interact with certain elements to produce particles that can cause ionization of gas. Thus alpha, beta, gamma, x-rays and neutrons can all cause the formation of ion pairs in a gas.

In a gas-filled detecting chamber circuit (Figure 6-2-1),

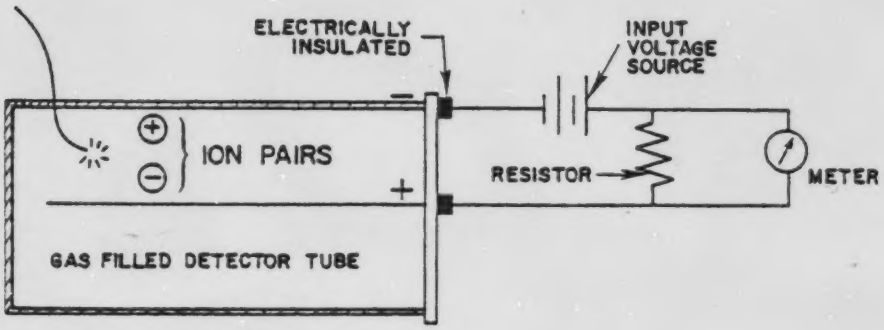


Figure 6-2-1. Gas-filled detecting chamber circuit.

the detecting chamber or tube consists of a gas-filled envelope containing a metal cylinder cathode and a coaxial wire anode. If nuclear radiation interacts in the chamber, the gas becomes ionized - the ions are drawn to the elec-

trodes by an electrical field established by voltage applied between the anode and cathode. The resulting ion movement is measured as potential across resistance R.

Potential developed across the resistor is the signal sent to the indicating circuit. The magnitude of this potential varies with applied voltage on the cathode and anode. By varying the applied voltage, the chamber can be operated in any of three regions:

Ionization.
Proportional.
Geiger-Mueller.

With no applied voltage across the anode and cathode, ion pairs formed by the incident radiation recombine to form neutral atoms (Figure 6-2-2). As applied voltage is increased from zero, ions move toward oppositely charged electrodes or to oppositely charged ions, depending on which at-

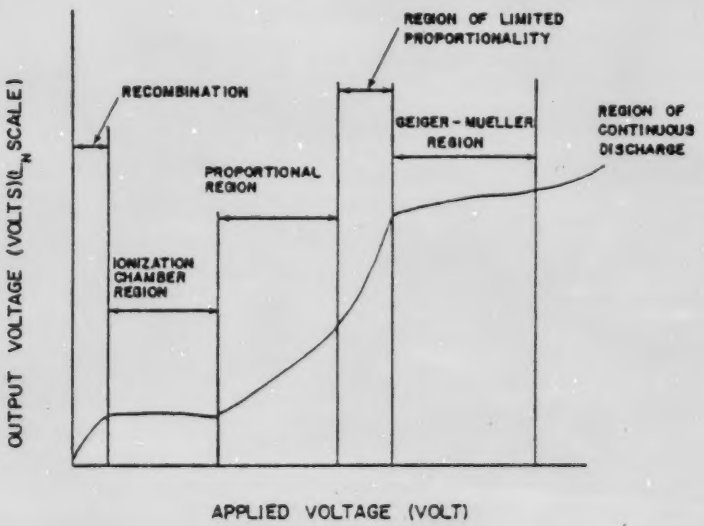


Figure 6-2-2. Output pulse height versus applied voltage (gas-filled detector).

tractive force is greater. At low applied voltages, ions drift toward electrodes with a high probability of recombination. But, as applied voltage is increased, the electric field in the chamber is increased, increasing the movement of ions toward the electrodes; thus, less recombination occurs. Eventually, an applied voltage is reached at which all formed ions are attracted to the electrodes and there is no recombination. The magnitude of this voltage is called the "saturation threshold of the ionization region."

If applied voltage is increased above this saturation threshold, no increase occurs in the ion current collected by the electrodes (ion current is constant). This magnitude of ion current, called "saturation current," carried by the primary ion pair, is produced by incident radiation.

The counting chamber is said to be operating as an ionization chamber when the magnitude of applied detector voltage results in a saturation ion current. The ionization chamber region may also be defined as the range of applied voltages where the gas amplification factor is unity. (Gas amplification factor is the ratio of ion pairs collected at the electrode to primary ion pairs formed by incident radiation.)

In the ionization region, pulse height is proportional to the number of primary ion pairs formed. Therefore, output pulse height is greater for particles having high specific ionization, such as alpha particles, than for lower ionizing radiations, such as betas and gammas.

Ionization chambers fall into two basic classes:

Pulse-type operation.
Mean-level operation.

A pulse-type chamber produces an output voltage pulse for each particle of radiation, causing an ionization event in the chamber. These output pulses are counted by a "scaler." Mean-level (steady voltage) ionization chambers produce an average voltage that varies with rate of occurrence of ionizing events.

If time between ionizing events is large (compared with discharge time through the resistor), the chamber is termed a pulse chamber. One advantage of a pulse chamber is that it can, with associated discriminating circuits, detect the better ionizers in the presence of considerable numbers of weak ionizers. Its output voltage pulse is greater for strongly ionizing particles and, by biasing the amplifier following the detecting chamber, the scaler responds to only large pulses.

If time between ionizing events is small, compared with discharge time through the resistor, a steady or mean-level voltage is developed. The magnitude of this average voltage is dependent upon rate of arrival of ionizing radiations.

Detectors operating in the ionization region offer two significant advantages:

Applied voltage requirement is low, eliminating need for large voltage systems.

Elaborate voltage stabilization system is unnecessary because gas amplification remains constant over a wide range of applied voltages.

Increasing applied voltage above the ionization region range results in the chamber entering the proportional region of operation. Under this higher voltage, primary ions are accelerated toward the electrodes with sufficient velocity to cause secondary ionizations to occur as they pass

through the gas. These secondary ions, formed by collisions with the gas, are accelerated by the electric field and cause further ionization. This ion multiplication, or gas amplification, is called "Townsend" or "avalanche" ionization.

Secondary ionization increases with increasing electric field strength. Field strength depends not only on applied voltage but also on chamber geometry. In basic cylindrical detectors, electric field strength is greatest in the vicinity of the central wire anode - it decreases in the outward radial direction. Secondary ionization (ion multiplication) then occurs around the central wire anode; electrons formed during avalanche ionization are collected at the anode, while heavier positive ions move slowly toward the cathode. It is positive ion movement (current) that determines output pulse across the resistance.

Output pulse has an initial rapid rise as positive ions move from the high strength field (near the anode) toward the cathode. If the chamber is followed by a circuit having a short time constant, the net result is a shorter discharge time and a smaller pulse. An advantage of this sort of pulse shaping is that the proportional chamber is capable of high counting rates. Although pulses are made smaller, they are still proportional to the initial ionization.

Another factor contributing to the high counting rates associated with proportional counters is the localized nature of this avalanche ionization. Secondary ionizations and ion avalanche, which occur near the anode, do not spread throughout the chamber or move along the anode; therefore, the chamber is capable of responding to other primary ionizing events (or ion avalanches) occurring at different points on the anode.

In the proportional region, gas amplification and pulse size vary with applied voltage. For a given applied voltage, the gas amplification factor is constant, and output pulse height is proportional to the amount of primary ionziation. The output voltage pulse is greater for strong ionizers than for the weak ionizers, which makes it possible to count strong ionizers in the presence of weak ionizers by the use of discriminating amplifiers. Also, the gas amplification factor, which is no longer unity, may be as large as 10^3. Such high gas amplification offers an advantage because less external amplification is needed to make the output pulses large enough to actuate a counter.

Proportional counting chambers offer these additional advantages:

Proportionality.
High counting rates.

One disadvantage of proportional counters is that a well regulated power supply is needed because gas amplification and pulse height both vary with applied voltage.

By increasing voltage through the proportional region, a point is finally reached at which gas amplification varies with the amount of primary ionization. From this point on, pulses are no longer directly proportional to the amount of primary ionization. Then gas amplification is no longer proportional to applied voltage, but also depends on primary ionization. This range of applied voltage, called the "limited proportionality region," is not useful for radiation monitoring.

As voltage is increased through this limited proportionality region, an applied voltage is reached at which output pulse height is the same for all incoming radiations. This voltage, called the "Geiger threshold," is the lower

end of a voltage range called "Geiger-Mueller region."

NEUTRON DETECTORS

Neutron detectors utilized in reactor control channels must be capable of providing instantaneous neutron flux information. (Remember: Alpha and beta particles ionize gas directly and gamma rays and x-rays produce secondary particles - free electrons - which cause ionization of gas in a gas-filled detector.) Neutrons, however, are neutral particles, and the probability of a neutron causing ionization by interaction with an orbital electron is very small. For this reason, neutron-electron interactions to produce ionization of gas in a detection chamber cannot be relied upon to produce the required ionizations necessary for accurate neutron flux monitoring.

Neutron interactions employed in neutron detectors fall into two major categories, scattering interactions and absorption interactions. Most commonly used - scattering interaction - is the elastic scattering of neutrons by a hydrogenous material which results in formation of recoil protons. Two absorption interactions commonly used are neutron-alpha and neutron-fission reactions. In each of these reactions, secondary particles ionize the detection gas.

Selection of the interaction to be used depends on the energy of neutrons to be detected. If the neutrons have high energy (fast neutrons), elastic scattering interaction is employed. If neutron energy is low (thermal neutrons), then neutron-alpha or neutron-fission interactions are used.

Because most nuclear reactors in use today depend on thermal neutrons to cause fission, only neutron-alpha and the neutron-fission interactions are discussed in this module.

FISSION CHAMBER

Monitoring neutron flux of a thermal neutron reactor can be satisfactorily accomplished by a fission chamber (Figure 6-2-3).

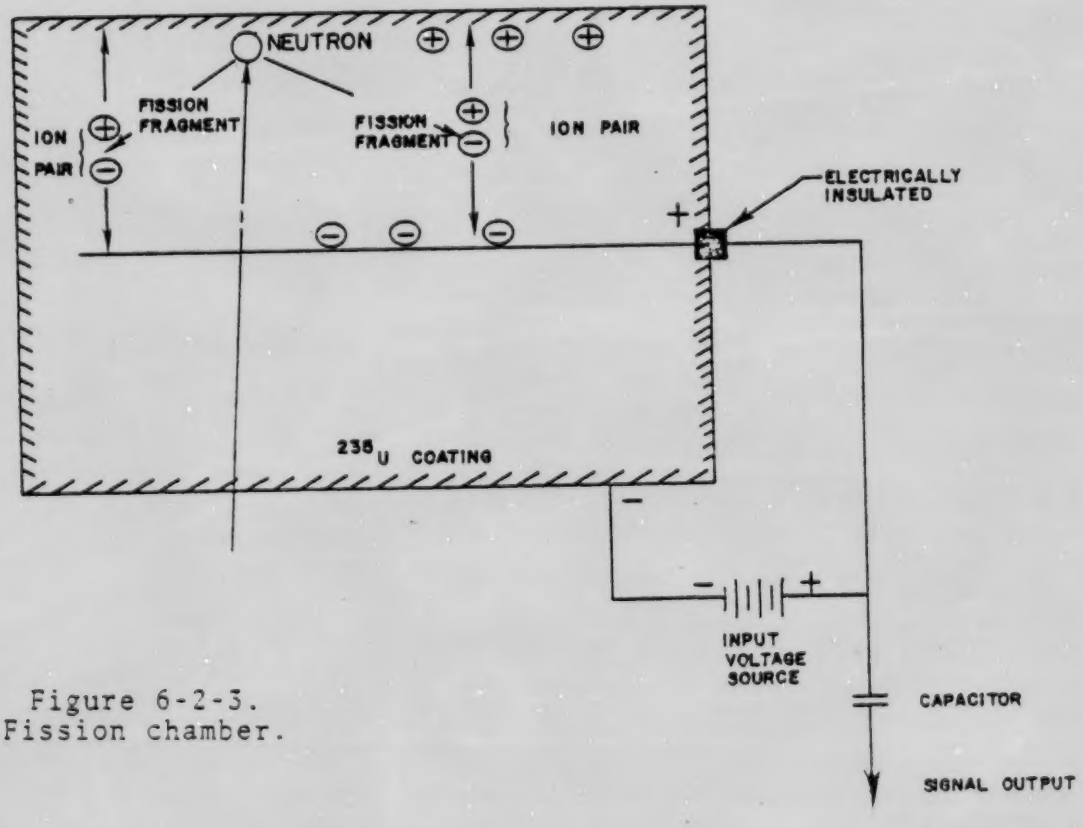


Figure 6-2-3.
Fission chamber.

A fission chamber is merely an ionization chamber containing a fissionable material (such as ^{235}U), generally in the form of a coating on the internal surface of the detector. When a thermal neutron enters the chamber, it is absorbed by the ^{235}U, and fission occurs. Resulting fission fragments cause ionization of the detecting gas, with the resulting ion pairs causing current to flow in the detector system, thus indicating the presence of neutrons:

$$^{235}U + n \rightarrow 2 \text{ fission fragments} + \text{neutrons} + \approx 200 \text{ MeV}.$$

Fission fragments formed during the neutron-fission reaction have much higher energies and greater ionizing power than secondary particles formed by gamma rays; therefore, they tend to overshadow the impulses resulting from gamma ionization. This characteristic allows the systems to tell the difference, and to ignore signals from gamma rays.

When a fission chamber is used, a circuit must also be provided that can discriminate against ionization resulting from alpha particle interaction with the detecting gas. The ^{235}U, which coats the detector, decays naturally by the emission of alpha particles, and failure to discriminate would cause the circuit to indicate a higher than actual neutron level.

BORON PROPORTIONAL COUNTERS

Neutron-alpha interaction with boron-10 also is widely used in thermal neutron detectors (Figure 6-2-4). Detectors

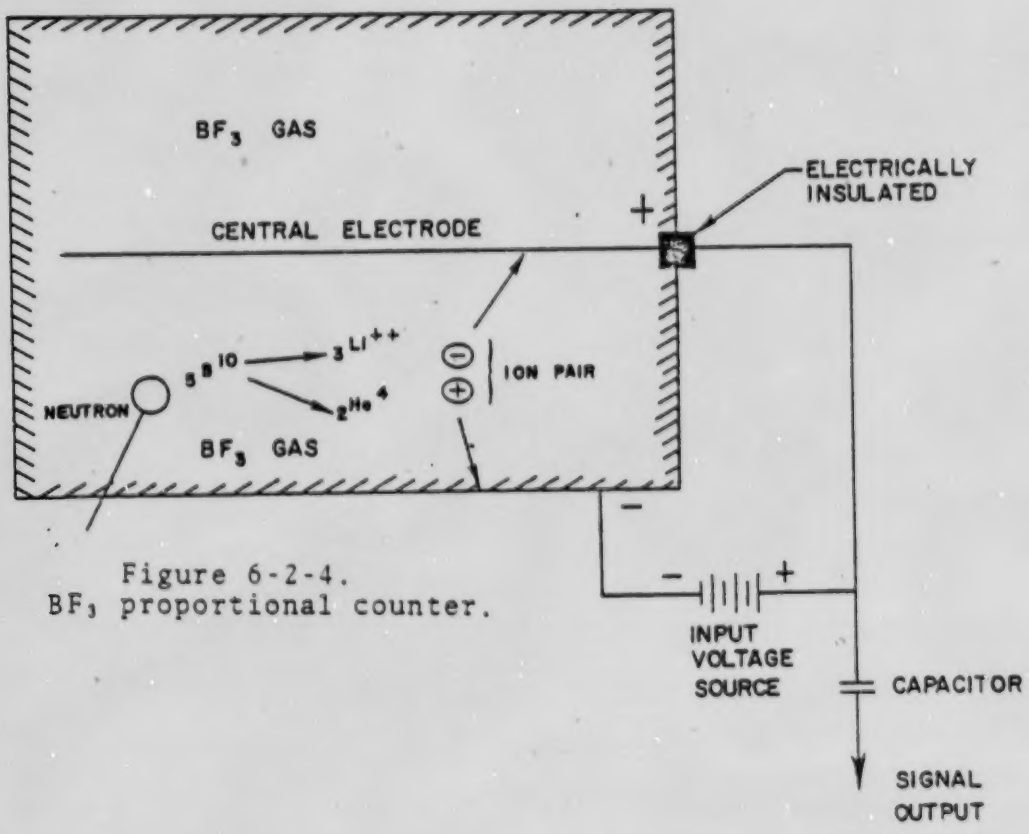


Figure 6-2-4.
BF_3 proportional counter.

based on this interaction usually are gas-filled proportional or ionization chambers, lined with a ^{10}B compound or containing a boron gas, such as boron-trifluoride (BF_3):

$$^{10}B + n \rightarrow {}^{7}Li + {}^{4}\alpha + 2.3 \text{ MeV}.$$

A thermal neutron is absorbed by the boron, forming a lithium atom, an alpha particle and 2.3 MeV of energy. The high-energy alpha particles are very strong ionizers, providing a large signal output from the chamber.

COMPENSATED ION CHAMBERS

Compensated ion chambers (Figure 6-2-5) provide accurate neutron flux information in the period and power ranges of reactor operation. Compensated ion chambers are so termed because the component of the signal due to ionization by gamma rays is balanced out of the final signal.

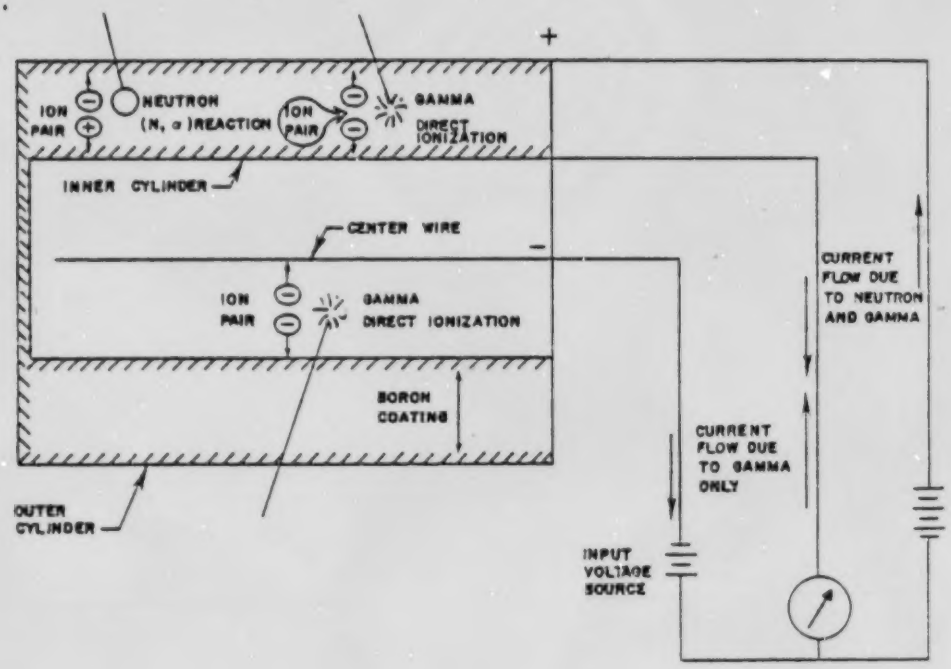


Figure 6-2-5. Compensated ion chamber.

The compensated ion chamber is essentially two differentially connected detecting volumes enclosed in a single case. One of two nitrogen filled volumes, coated with boron, is sensitive to both neutrons and gamma rays. The other volume, not coated with boron, is sensitive to only gamma radiation. The differential connection between the two permits cancellation of the gamma produced current.

This chamber is especially useful at low power levels, when neutron flux level is low compared with gamma ray intensity.

UNCOMPENSATED ION CHAMBERS

Uncompensated ion chambers are usually used in power ranges in which neutron signal current is large (compared with gamma signal). An uncompensated ion chamber (Figure 6-2-6) has a single nitrogen filled volume that is sensi-

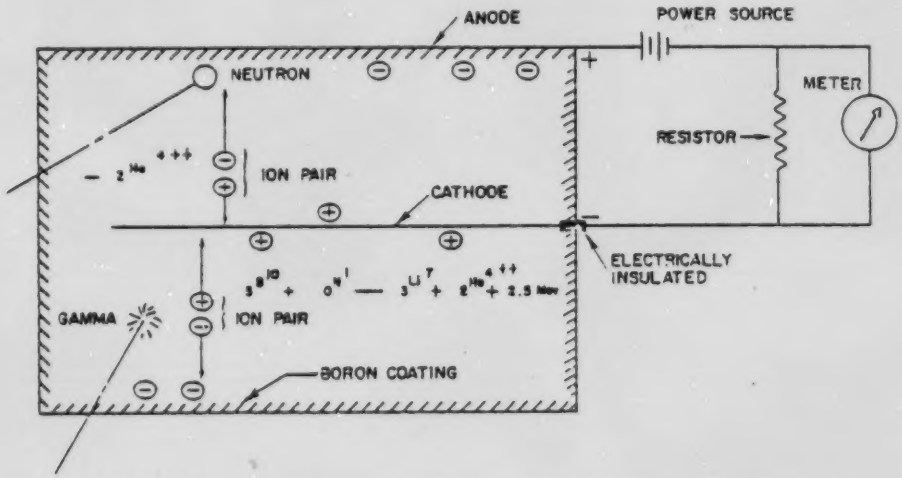


Figure 6-2-6. Uncompensated ion chamber.

tive to both neutron and gamma radiation; however, relatively high neutron flux makes the effect of gamma radiation much less significant, precluding any need for compensation.

NEUTRON THERMOPILES

Many instruments, other than those previously discussed, are used in reactor control (e.g., the neutron thermopile). A neutron thermopile is comprised of several thermocouples connected in series, but having alternate junctions, coated with boron (Figure 6-2-7). Heat

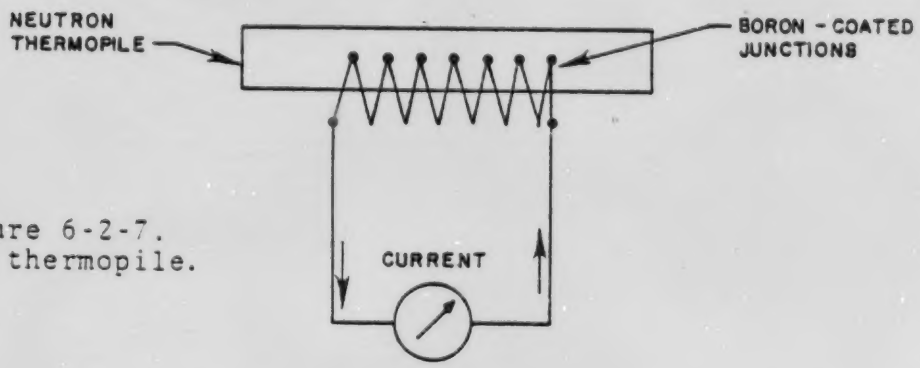


Figure 6-2-7.
Boron thermopile.

generated when neutrons interact with the boron is capable of producing a significant output voltage: a thermal flux of 10^{12} n/cm^2-s causes an output voltage of about 10 millivolts.

Advantages of this type of instrument include:

Small size.

Ruggedness and reliability.

Low high-voltage insulation requirement.

Disadvantages include:

Boron depletion due to high neutron flux.

Slow response time.

EXERCISES

1. Which counters are used for low flux levels? Explain why.
2. Which counters are used for high flux levels? Explain why.
3. What units of measurement are used by counters? If not in flux units, how do they relate to flux units?
4. What effect does neutron energy have on measurements?
5. In a nuclear reactor, what is done to correct for ionizations caused by gammas?
6. How do measured values compare with accepted values (reactor) or calculated values (source)? Explain any differences.

MATERIALS

1 neutron source or small nuclear reactor.
1 fission chamber.
1 compensated ion chamber.
1 uncompensated ion chamber.
1 BF_3 proportional counter.

PROCEDURES

1. Use a neutron source of known value (neutrons/second); calculate neutron flux at 10 different distances from source. Record results on Data Table 6-2-1.
2. Use a BF_3 proportional counter; measure neutron flux at the same distances. Record results on Data Table 6-2-1.
3. Compare results of Procedures 1 and 2; calculate variations (if any); record differences on Data Table 6-2-1.
4. Plot distances-versus-flux calculations from Procedure 1.
5. Plot distances-versus-flux calculations from Procedure 2.

DATA TABLE

DATA TABLE 6-2-1

Distance in Meters	Neutron Flux Calculations	BF_3 Measurements	Difference

Glasstone, Samuel. Principles of Nuclear Reactor Engineering. Princeton, NJ: Van Nostrand, 1961.

Pedersen, Knud B.; Sasscer, Donald S.; Plaza, Herbierto; Gileadi, Aviva E.; Brown-Campos, Richard; and Holyoak, Robert H. Applied Nuclear Power Engineering for Practicing Engineers. Boston: Cahners Books, 1972.

Schultz, M.A. Control of Nuclear Reactors and Power Plants. 2nd ed. New York: McGraw-Hill, 1962.

1. List all types of neutron detectors commonly used:

2. Sketch the following types of neutron detectors and briefly explain operation of each:

   Fission chamber.

   BF_3 proportional counter.

   Compensated ion chamber.

   Uncompensated ion chamber.

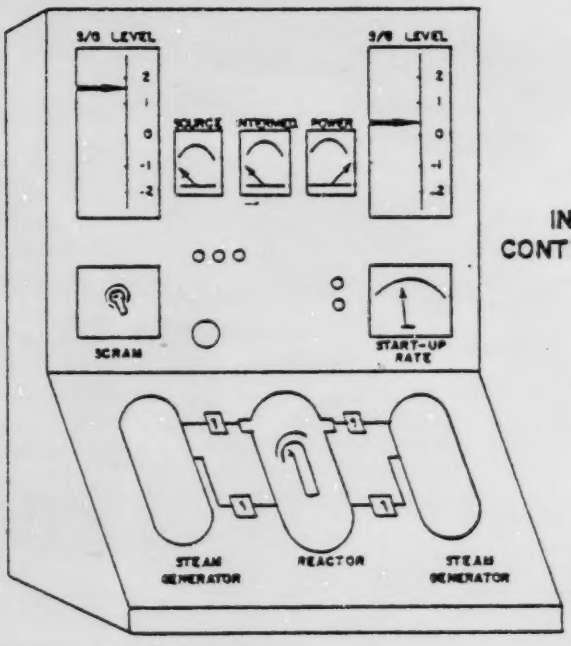
Neutron thermopile.

3. In what range of neutron flux and reactor power is each type of detector in question 2 used? Briefly explain why:

NUCLEAR TECHNOLOGY

MODULE 6-3 NEUTRON FLUX SIGNAL CONDITIONING. -

JOSEPH A. BURACK



INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

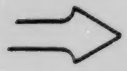
COURSE 6

TERC-SW

TECHNICAL EDUCATION RESEARCH CENTER — SOUTHWEST
4201 LAKE SHORE DRIVE WACO, TEXAS

COURSE MODULES

COURSE 6 INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS



MODULE 6-1 Neutron Monitoring Systems

MODULE 6-2 Neutron Sensors

MODULE 6-3 Neutron Flux Signal Conditioning

MODULE 6-4 Control-Rod Drives and Indicating Systems

MODULE 6-5 Instrumentation Power Supplies

MODULE 6-6 Installation of Instrumentation Systems

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INTRODUCTION

In the previous module the student studied operating details of typical neutron detection devices, such as fission and ionization chambers. In this module the student learns the electrical output characteristics of these devices, and the methods employed to process (signal condition) them prior to their input to a display device such as a chart recorder or rate meter.

Reactor instrumentation systems detect, measure and indicate nuclear flux in a reactor. They protect the reactor, plant equipment and plant personnel by signaling when reactor flux exceeds a predetermined level, or flux rate increase exceeds a constant value. This module describes methods of detector signal analysis and conditioning used to monitor nuclear flux.

MODULE PREREQUISITES

The student must have completed a basic course in elementary electronics and be familiar with the concept of operational amplifiers.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List various steps of signal conditioning, from detector output to display device, for each major detection system discussed.
2. Describe function of each component in a system.
3. Describe various operational amplifier circuits for linear and logarithmic gain, and discuss their associated uses.
4. Assemble a typical neutron flux detection circuit from basic components (detector, amplifier and display device).
5. Use a neutron source with a detection system to trace and sketch a signal at various subsystems.

NEUTRON FLUX MEASURING SYSTEMS

Three distinct systems used to measure neutron flux include:

- Startup (or source) range system, which covers a range from approximately 0 to 0.01% of full power.
- Intermediate range system, which overlaps source range by covering a region from approximately 0.005 to 100% of full power.
- Power range system, which covers a region from 0.1% to 100% (or more) of full power.

These divisions of the detection range are necessary, not only because neutron flux covers approximately 14 orders of magnitude from startup to full power, but also because of the limitations of the detection devices used in each of the above regions.

STARTUP (SOURCE RANGE)

This range typically covers the lower four or five decades of the neutron flux level. The exact magnitudes involved depend on whether the detectors are situated in the active core area or outside the core in the leakage region.

Either a BF_3 proportional counter or a fission chamber most often is used. Advantages of a BF_3 proportional counter are that - with fairly simple electronics - 1) it can easily distinguish neutron events in the presence of a low gamma flux, and 2) it often is situated outside the active core area. In the presence of high gamma flux (as found inside the core), a proportional counter is replaced by a fission chamber, which

is insensitive to gamma radiation.

In such a system (Figure 6-3-1), a high-voltage power supply operates in the detector's plateau region, on the order

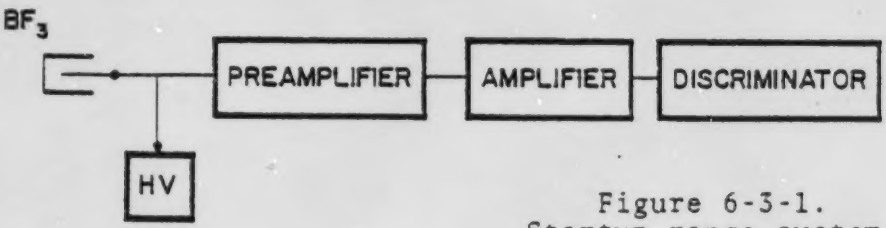


Figure 6-3-1.
Startup range system.

of 750 volts. Because output pulse height is proportional to applied voltage, the power supply must be fairly stable, thus it usually is regulated to within 1 or 2 percent.

Output from a BF_3 tube is on the order of 20 to 200 mV. A mismatch between the high output impedance (of the counter) and the input impedance (to the cable) results in extensive attenuation of the signal; therefore, the preamplifier (Figure 6-3-2) serves as a unity gain impedance match between

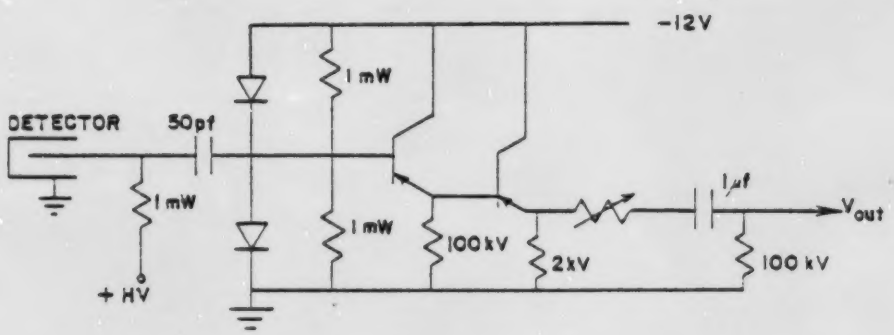


Figure 6-3-2. Preamplifier circuit.

the detector and the transmission cable, normally located as close as possible to the detector.

Diodes in the preamplifier circuit limit input voltage to the preamplifier, protecting it during transients (e.g, during switching-on of high-voltage power supply). The variable resistor in the output matches transmission cable impedance to preamplifier output impedance.

If a fission chamber is used, the preamplifier usually has some forward gain. Forward gain of the fission chamber low-noise preamplifier circuit (Figure 6-3-3) is either ± 2 or ± 16, depending on gain switch selection. Note: Each of the two preamplifiers illustrated is a.c.-coupled between detector output and amplifier input.

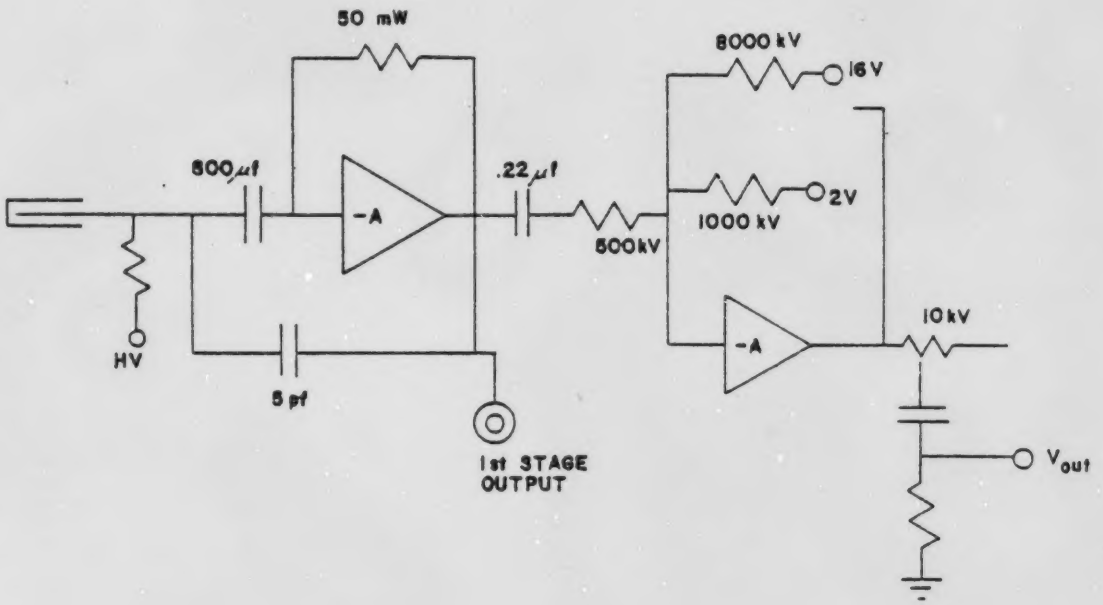


Figure 6-3-3. Low-noise preamplifier circuit.

The next subsystem (Figure 6-3-1) is a linear amplifier with a gain on the order of 10^3 or more, which raises the

voltage level of the signal from the millivolt to the volt range (10 mV to 10 V).

Both the amplifier and preamplifier must meet several fairly critical requirements, including:

High order of gain stability.

Free from oscillations in voltage.

Linear pulse reproduction, with fast rise times.

The latter requirement implies linear gain over a wide range of frequencies.

At the amplifier output, the system has an amplified reproduction of the detector pulse.

The portion of the startup system considered has pulses caused by both gamma and neutron interactions in the detector; however, the pulse amplitude caused by neutrons is generally greater than that produced by gamma interaction.

A device called a discriminator (Figure 6-3-4) is used to distinguish between these events. Discriminator output is a standard pulse whenever the amplitude of the input pulse exceeds a preset value. This output can be used to drive counting rate circuits to provide visual indications, alarms and trip points.

In a discriminator circuit, resistor values are chosen such that in the steady-state condition, Q_1 is turned off and Q_2 is turned on, holding output voltage low. Triggering voltage (V_{io}) level is adjustable by a variable resistor. As V_{in} increases above V_{io}, transistor Q_1 is eventually driven into a conducting state, allowing C_2 to rapidly discharge, bringing base voltage at Q_2 to zero and driving it to a nonconducting state, which allows V_{out} to go high. Meanwhile, Q_2 is held off until the charge buildup on C_2 drives it back to a conducting state, which brings V_{out} low. The diode ensures a constant output pulse width, independent of the pulse rate, to drive a pulse counting rate circuit.

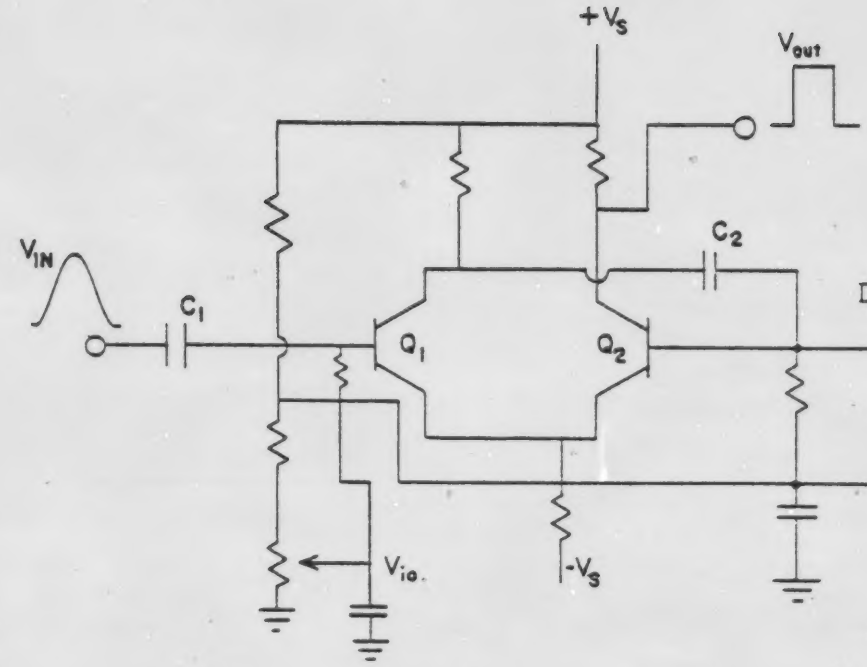


Figure 6-3-4.
Discriminator.

A pulse count-rate circuit (Figure 6-3-5) is essentially an integrator. Voltage pulses are integrated with respect

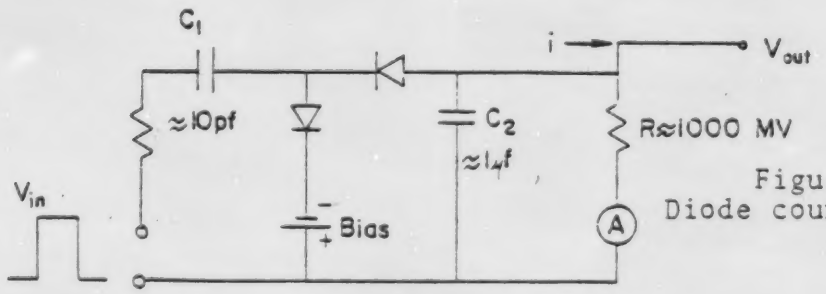


Figure 6-3-5.
Diode count-rate circuit.

to time. Output d.c. voltage, therefore is proportional to the number of counts per second in the input signal.

If input pulses are identical, and of equal width, a

fixed amount of charge is placed on capacitor C_2 each time a pulse occurs. This charge dissipates through short resitor R_2 and an ammeter. The average potential across capacitor C_2 is proportional to the pulse rate.

As indicated earlier, startup circuitry monitors flux over four to five decades. But, if preferred, the counting rate circuit output can be made proportional to the logarithm of the counting rate by inserting a nonlinear resistance with a logarithmic input/output characteristic in place of R_2. Also, diodes can be installed that have logarithmic responses in low current regions where the diode is just beginning to conduct.

During startup, a reactor operator is more concerned with rate of flux change than with absolute flux level. Often, this rate of change is expressed in terms of reactor period - time required for the flux level to change by a factor of the exponential e (2.72). This period can be determined by looking at the rate of change of a current proportional to the logarithm of the flux level. In a reactor, flux level growth is exponential:

$$I \alpha \text{ Ln } Ae^{t/T} \qquad \text{Equation 6-3-1 (Equation = Eq.)}$$

where

α = proportional to.
I = current.
A = constant.
t = time.
T = reactor period.

The period circuit (Figure 6-3-6) produces a d.c. output voltage inversely proportional to the reactor period.

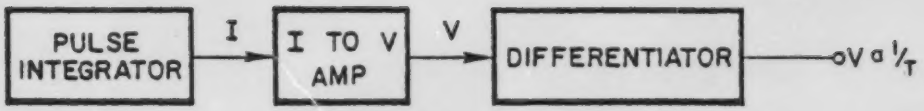


Figure 6-3-6. Reactor period circuit.

INTERMEDIATE RANGE

The intermediate, or "wide" range channel covers about six to eight decades of neutron flux level. Both linear and logarithmic channels are used. If in-core measurement is desired, fission chambers are used; however, compensated-ion chambers are usually used as out-of-core detectors. In either case, detectors are operated in the constant ionization mode (that is, a continuous output current is observed, rather than discrete pulses).

A fission chamber circuit (Figure 6-3-7) would be identical to the linear circuit (for a compensated ion chamber).

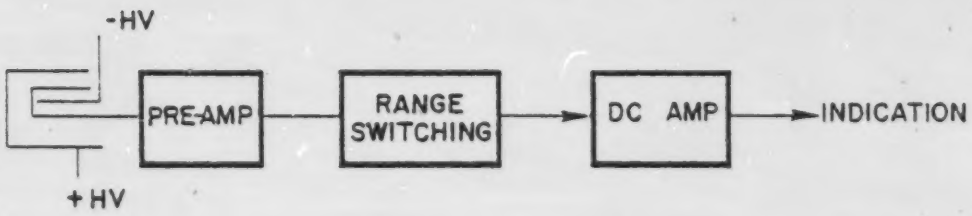
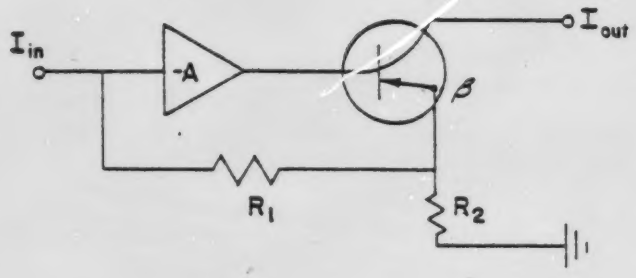


Figure 6-3-7. Linear circuit for a compensated-ion chamber.

A preamplifier is often a feedback-stabilized, current-gain operational amplifier (Figure 6-3-8). Gain is determined



$$I_{out} = \frac{R_1}{R_2}\left(1 - \frac{1}{\beta}\right) I_{in}$$

if $R_1 >>> R_2$

Figure 6-3-8. Preamplifier circuit.

by the R_1/R_2 resistor ratio. A simple switch allows selection of various precision-wound resistors. Voltage drop across these resistors serves as input to the d.c. amplifier. Output from the d.c. amplifier, which can be on the order of 0 to 10 V, is used to drive indicators and trip devices.

POWER RANGE

Circuitry used in the power range is identical to the linear intermediate range system discussed previously. Linear intermediate range system discussed previously. Linear circuitry is used because this range provides fine control for reactor monitoring, reactor control and trip functions. In general, higher neutron densities in this power range allow use of uncompensated-ion chambers if out-of-core instrumentation is used.

TRIP CIRCUITS

These circuits usually drive a relay in the reactor protective system to initiate a trip. Output voltage of the measurement circuits, discussed previously, is monitored and compared with a reference voltage representing the desired trip point. It is highly desirable that the trip occurs at exactly the instant these two voltages are equal, regardless of how fast or slow the measurement voltage approaches the trip point value. For this reason, a bistable vibrator circuit that functions very similarly to the discriminator circuit (Figure 6-3-4) is almost universally used. High output from a bistable (Figure 6-3-9) drives a triggering circuit that causes the silicon controlled rectifier (SCR) to conduct, energizing the trip coil to the reactor protective system (RPS).

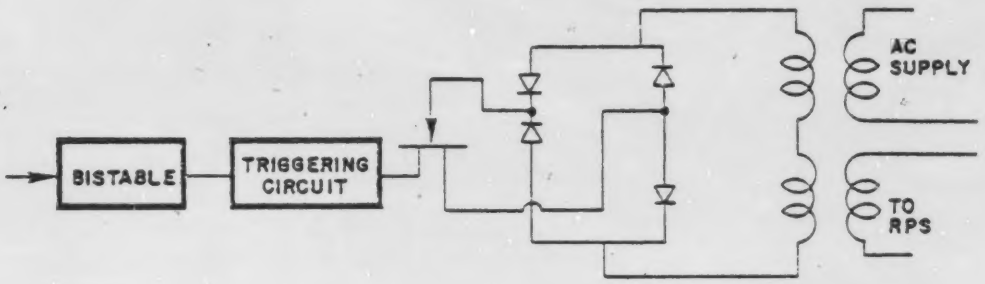


Figure 6-3-9. Discriminator circuit with bistable.

Typically neutron flux measurement systems (Figure 6-3-10) currently are in use in power reactors.

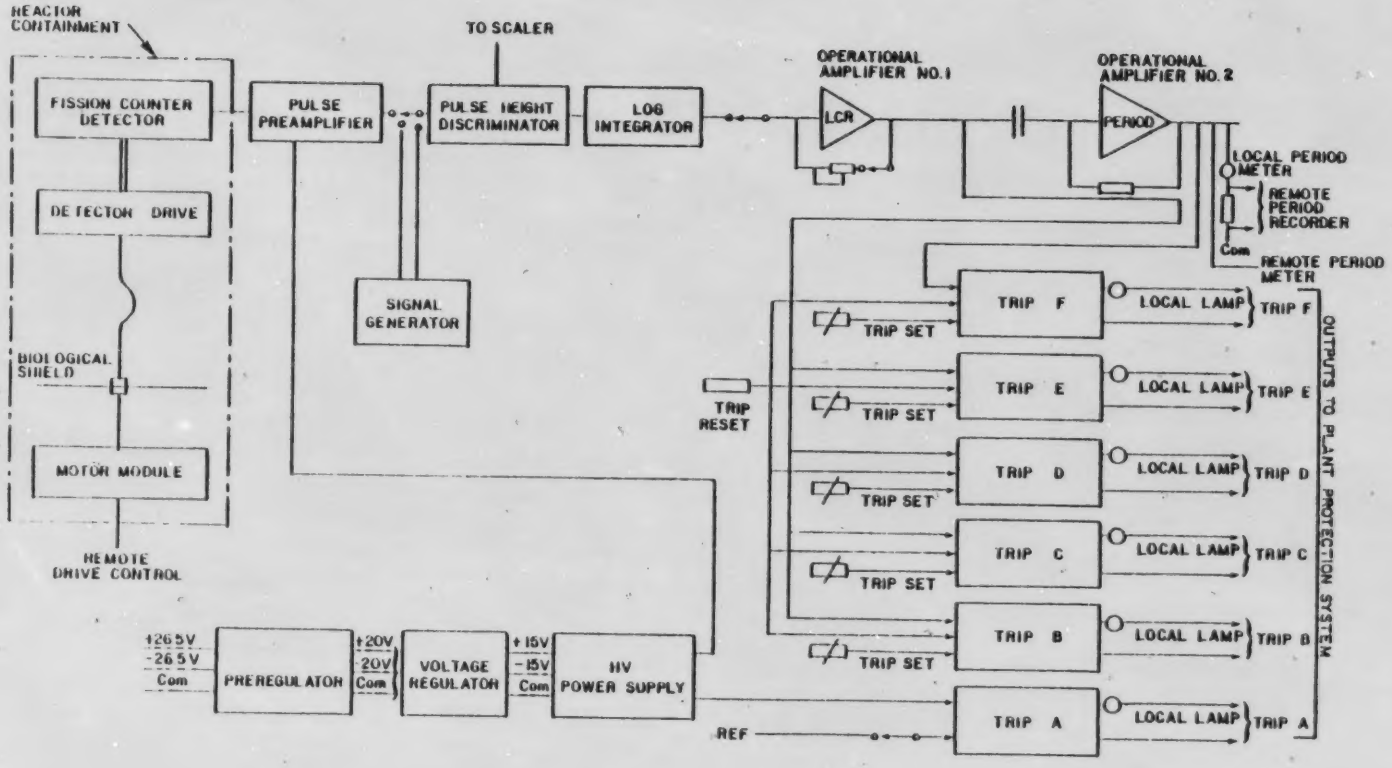


Figure 6-3-10. Neutron-flux measurement system.

EXERCISES

1. Identify:

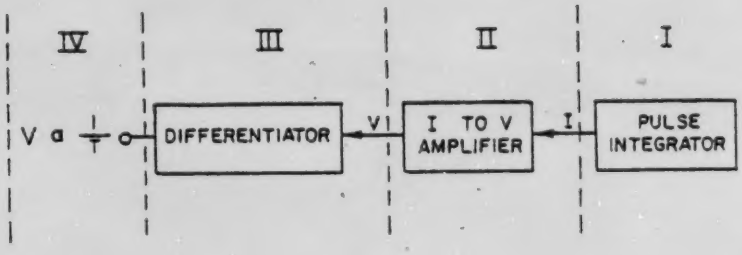


Figure 6-3-11. Block diagram of a _____ _____ circuit.

2. Describe briefly the function of each segment: I, II, III and IV.
3. List three kinds of neutron flux measuring systems (described in this module); use name given in module; give general range of each in mV or V.
4. Sketch a block diagram of each system.

MATERIALS

1 neutron detector.
1 amplifier circuit.
1 oscilloscope.
1 neutron source.

PROCEDURES

1. From basic components (detector, amplifier and display device) provided by instructor, assemble a neutron flux detection circuit.
2. Use circuit assembled in 1, and a neutron source provided by instructor; trace and sketch signal.

DATA TABLE

None.

REFERENCE MATERIALS

Boland, James F. Nuclear Reactor Instrumentation (In-Core). Gordon and Breach Science Publishers, 1970.

Kowalski, E. Nuclear Electronics. Springer-Verlag, 1970.

Price, William J. Nuclear Radiation Protection. New York: McGraw-Hill, 1964.

Zinn, W.H., ed. Reactor Handbook - Volume IV, Engineering. New York: John Wiley & Sons, 1964.

1. List various steps of signal conditioning, from detector output to display device, for each of the following:

Startup Range System	Intermediate Range System	Power Range System

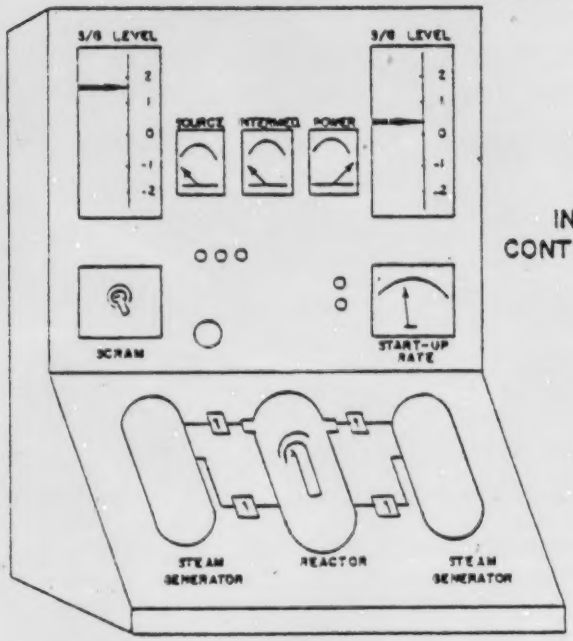
2. List and discuss function of each component in three systems identified above:

3. Briefly describe operational amplifier circuits described in this module; define use of each:

NUCLEAR TECHNOLOGY

MODULE 6-4 CONTROL-ROD DRIVES AND INDICATING SYSTEMS. -

JOSEPH A. BURACK



INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

COURSE 6

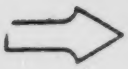
TERC-SW

TECHNICAL EDUCATION RESEARCH CENTER — SOUTHWEST
4201 LAKE SHORE DRIVE WACO, TEXAS

3 COURSE MODULES

COURSE 6

INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS



MODULE 6-1 Neutron Monitoring Systems

MODULE 6-2 Neutron Sensors

MODULE 6-3 Neutron Flux Signal Conditioning

MODULE 6-4 Control-Rod Drives and Indicating Systems

MODULE 6-5 Instrumentation Power Supplies

MODULE 6-6 Installation of Instrumentation Systems

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INTRODUCTION

The purpose of this module is to introduce the student to basic devices and systems used to control the operation of a nuclear reactor.

MODULE PREREQUISITES

The student should have completed the previous modules in this Course.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List and discuss:
   - Types of nonsolid control element systems.
   - Types of solid control element systems.
   - Various shapes of control rods.
   - Various materials from which control rods are made.
   - Different methods of control-rod drive.
2. With diagrams, describe operation of a control-rod drive system.

NONSOLID CONTROL ELEMENT SYSTEMS

There are three types of nonsolid control element systems.

REFLECTOR-MODERATOR CONTROL SYSTEM

Some reactors utilize the reflector level, moderator level, or both to control fission rate (reactor reactivity is controlled by amount of neutron leakage occurring). Reflector-moderator control systems are not extensively used in America, and are mentioned only because of their simplicity.

FUEL-LEVEL CONTROL

This control method, used only in experimental reactors, adjusts fuel quantity (liquid form) as necessary to give either a critical or noncritical configuration.

LIQUID POISON CONTROL

The liquid used as a neutron poison is a mixture of neutron absorbing materials, such as boron, mercury and water. The liquid neutron absorber (Figure 6-4-1) is injected into a separate loop within the reactor core or mixed with the reactor coolant. Density of the poison is continually adjusted to maintain desired criticality. In a liquid-rod system, poison is maintained at a specified concentra-

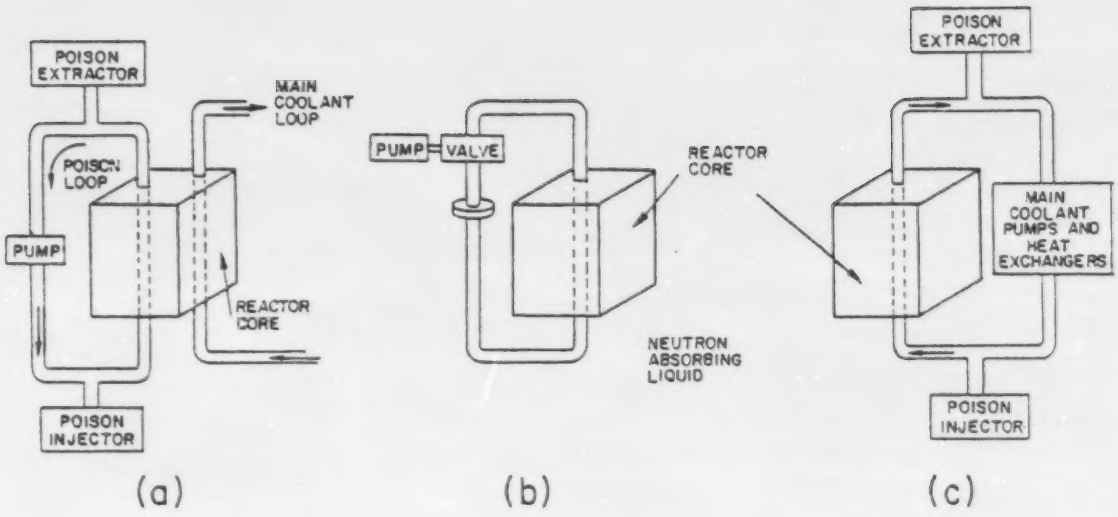

Figure 6-4-1. Liquid poison control systems: (a) liquid poison, separate loop; (b) liquid-rod system; (c) liquid poison injected into primary coolant loop.

tion within the core. The boron poison injection system is widely used in pressurized water reactors (PWR) for fine control.

The advent of large power reactors with large fuel inventories, and the need for minimization of shutdown time for refueling, has resulted in large built-in excess reactivities. Costs of solid control elements and the flux shadowing (caused by a large number of solid elements) also incluenced the rise of liquid poison control systems.

Liquid poison control still may be used in conjunction with solid control rods (as safety rods and control rods).

SOLID CONTROL ELEMENT SYSTEMS

The basic use of control elements, as previously mentioned, is to remove neutrons from the core. Many unique systems have been proposed and attempted, but only one is used in present day reactors. (One method, not in use, employed solid control rods inserted into the reactor reflector installed at the core periphery; rotation of the absorber-reflector assembly increased or decreased core reactivity.)

The most common solid control scheme employs rods inserted directly into the reactor core (Figure 6-4-2). While

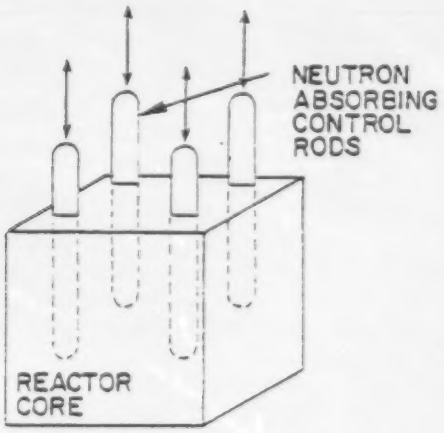

Figure 6-4-2.
Control rods in core.

this method of control is presently the most popular, it is not without problems. Solid absorptive control rods inserted directly into the core can cause severe flux depressions and hot spots, which must be compensated for by fuel modifications and other techniques. On the other hand, selective use of solid absorptive control elements at cer-

tain points within the core can attain an almost ideal flat-flux profile.

Many different geometries for control rods have been conceived (Figure 6-4-3) to divide reactor fuel into much smaller masses.

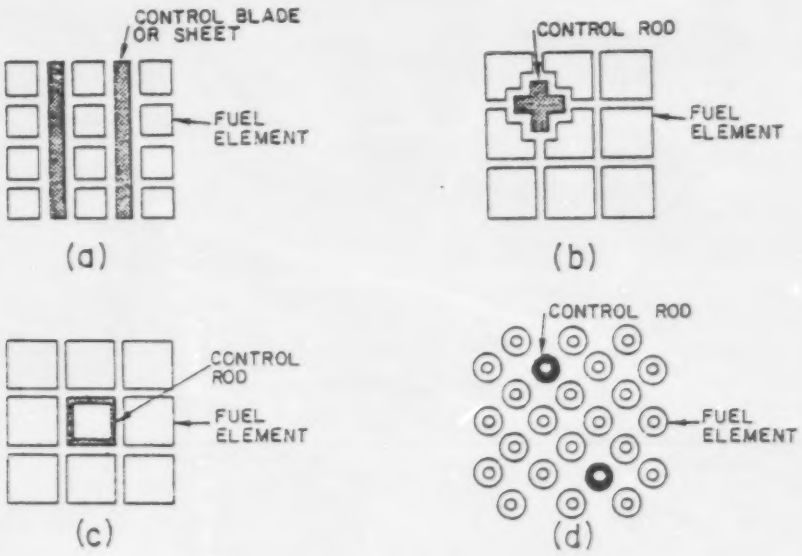

Figure 6-4-3. Control rod geometries: (a) blade or slab control; (b) cruciform rod; (c) box-type rod; (d) cylindrical rod.

A typical PWR control assembly (Figure 6-4-4) might incorporate one or more of these geometries, as might a BWR assembly (Figure 6-4-5).

Longitudinal variations of control elements (Figure 6-4-6) may utilize (a) a void-followed control element, (b) a fuel-followed control element or (c) a void-followed fuel element.

The material of which a control rod is made must possess numerous near-ideal properties:

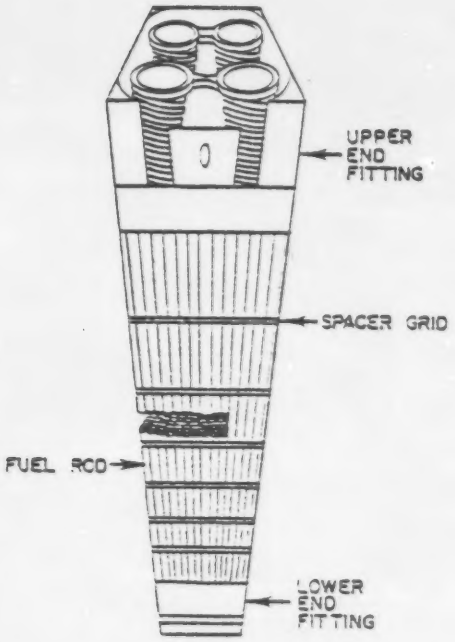

Figure 6-4-4.
Typical PWR control-rod assembly.

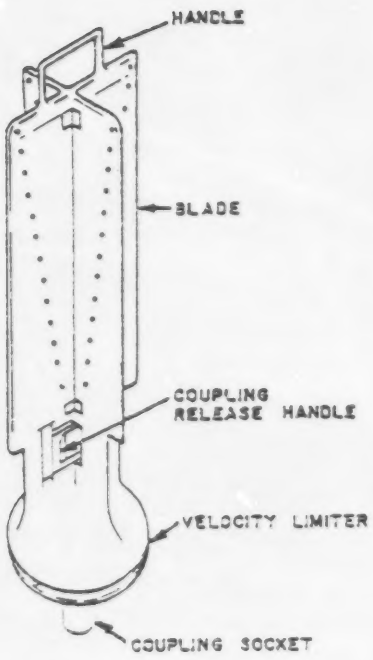

Figure 6-4-5.
Typical BWR control-rod assembly.

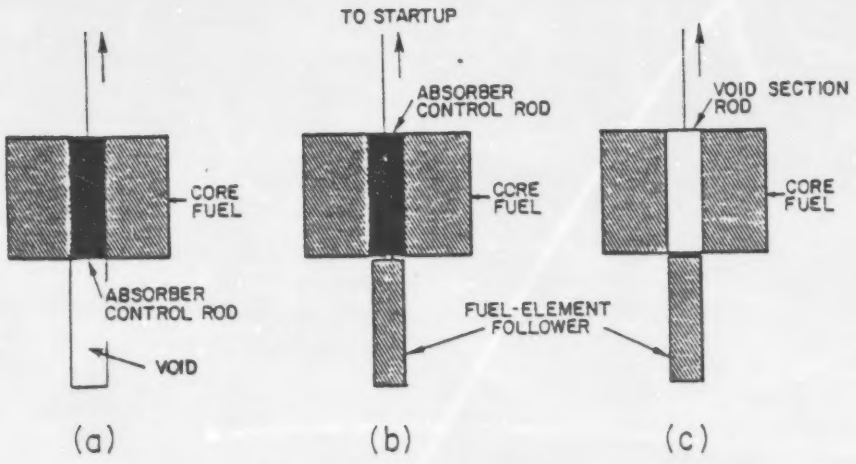

Figure 6-4-6. Control rods.

High absorption cross section for neutrons of all energies.

Good mechanical properties for ease of machining and forming.

Corrosion and erosion resistance, or capability of being clad for such protection.

Radiation damage resistance [high resistance to neutron embrittlement and swelling, and low yield of (n,α) reactions).

Low atomic mass, high density and a large number of absorber nuclei per unit volume.

Relatively low expense, compared with other reactor grade components.

No one element completely satisfies all these requirements; therefore, compromises have been made. Examples of the most commonly used control element materials include:

Boron (in the form of ^{10}B), widely used in combination

with carbide poured as a solid and as a liquid in the form of boric acid. Boron has a fairly high thermal neutron absorption cross section and is inexpensive.

Cadmium (in the isotope ^{113}Cd), widely used as a control element, has a high thermal neutron absorption cross section and is relatively inexpensive. But it has a low melting point of about 300°C (540°F) and it alloys poorly.

Hafnium (in the isotope H_f) is fairly radiation resistant and has a good resistance to corrosion. Unfortunately, it is expensive and difficult to machine.

Gadolinium has a high thermal cross section and is relatively inexpensive.

Europium has characteristics similar to hafnium but is somewhat expensive.

Silver.

Indium.

Gold.

INTERNAL AND EXTERNAL THIMBLES

The type of reactor used affects method of installation of the control element and its drive mechanism. Reactors are basically characterized as nonpressurized or pressurized.

Nonpressurized reactors, for the most part, are test, research or experimental reactors operating at room temperature and atmospheric pressure. Control mechanisms for this group use basically simple designs that allow easy accessibility for maintenance.

Pressurized reactors, on the other hand, because of their high temperatures and high pressures, require more involved designs (Figure 6-4-7). The mounting and drive

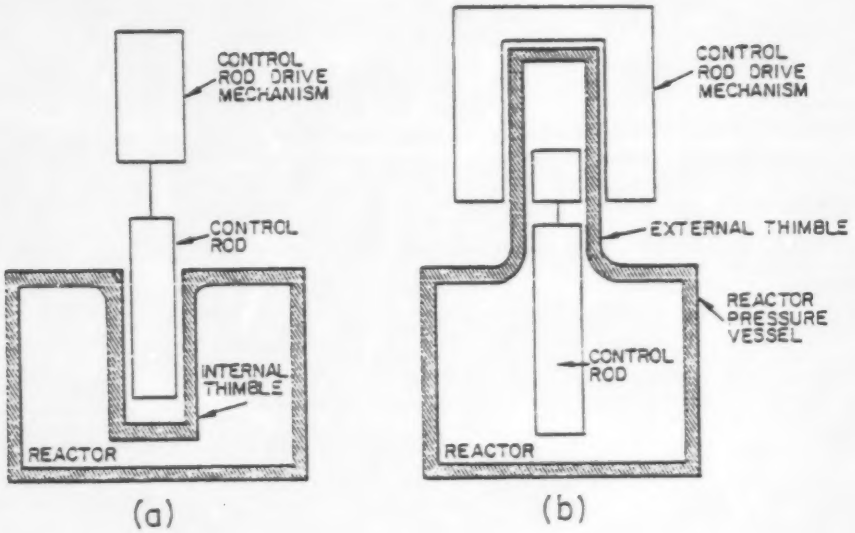

Figure 6-4-7. Pressurized reactor thimbles: (a) internal thimble; (b) external thimble.

arrangement for an internal thimble is not subject to reactor vessel pressures, as it is for an external thimble.

CONTROL ELEMENT DRIVE MECHANISMS

The rack-and-pinion rod-drive mechanism is one of the simplest methods for control element movement (Figure 6-4-8).

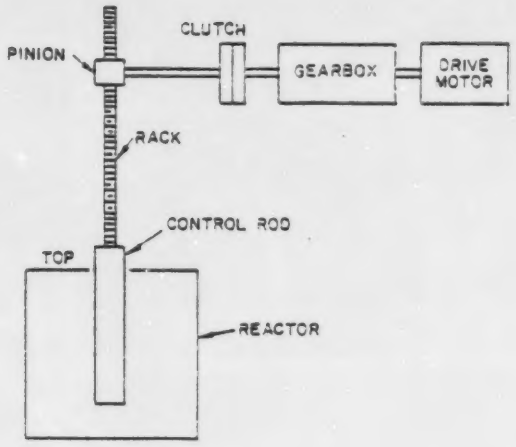

Figure 6-4-8.
Rack-and-pinion drive for control rod.

A drive motor turns the pinion via a gear box and clutch. Pinion movement in either direction causes the rack, to which the control rod is affixed, to move up or down. A similar arrangement, with the clutch removed (Figure 6-4-9),

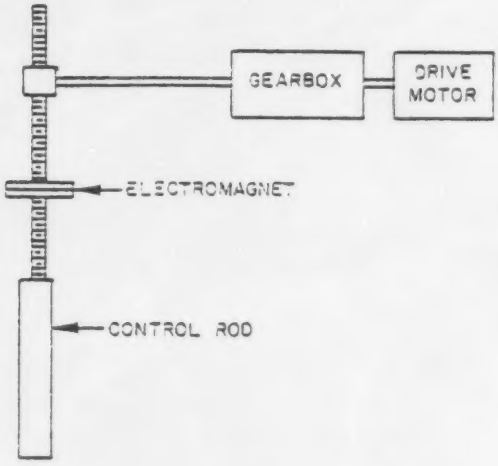

Figure 6-4-9.
Rack-and-pinion drive without clutch and with electromagnet.

is installed between the rack and the control element. In either case, the clutch (or electromagnet) is designed to

instantly disengage, providing "scram" capabilities to the control element.

Another simple control element drive mechanism employs a movable-nut, fixed-screw type arrangement (Figure 6-4-10a).

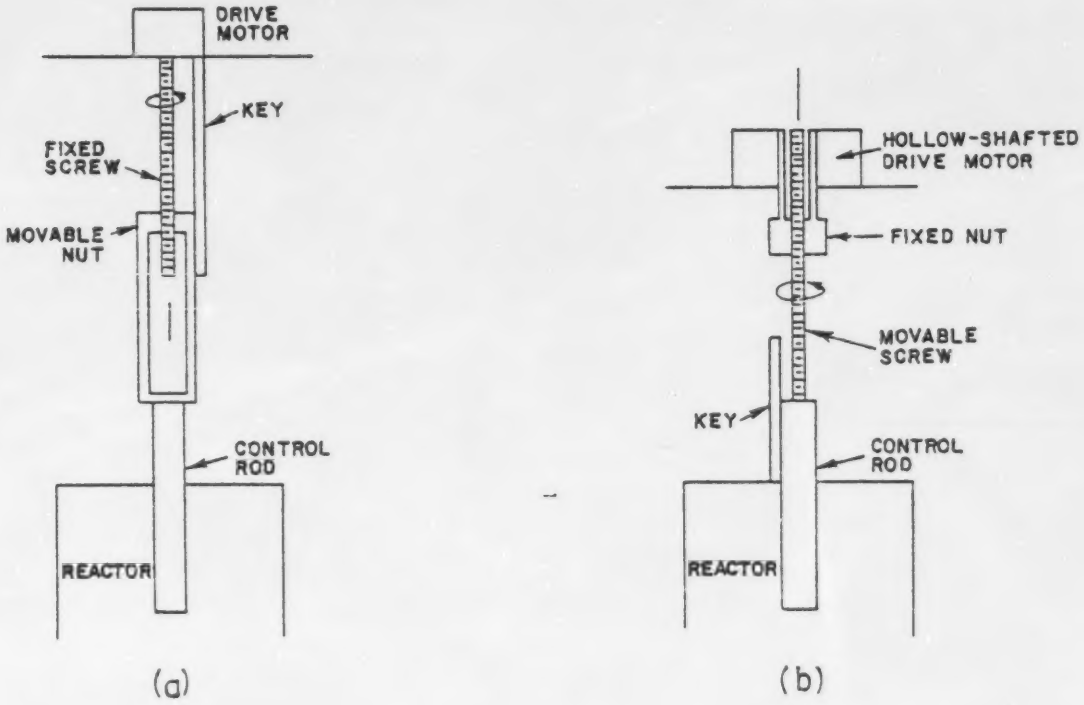

Figure 6-4-10. Screw-and-nut control-rod drives.

The drive motor turns the screw in either direction, and the nut, to which the rod is attached, moves up or down. In the fixed-nut/movable-screw arrangement (Figure 10-6-10b), the drive motor rotates the nut and the screw moves up and down.

In a magnetic feedthrough (control element drive mechanism) (Figure 6-4-11), the magnetic slug attached to the control rod incorporates an external thimble. This thimble,

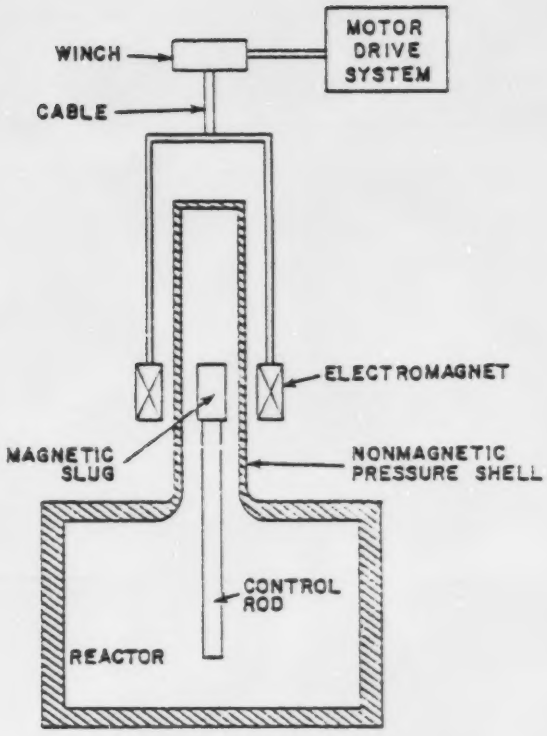

Figure 6-4-11.
Magnetic feedthrough for pressurized reactor drive system.

made of a nonmagnetic material, has an electromagnet, which is attached to some sort of drive system around its periphery. When the electromagnet is energized, the magnetic slug positions itself within the center of the magnetic field. Raising or lowering the electromagnet causes the slug to follow, and causes subsequent movement of the control rod. De-energizing the electromagnetic gives scram capability to this system.

The magnetic-jack rod-drive mechanism, a linear motor, moves the control elements in a series of finite steps. As its name implies, this mechanism jacks the control rods up and down by means of a series of stacked coils. Two versions of this system (Figure 6-4-12) are in use:

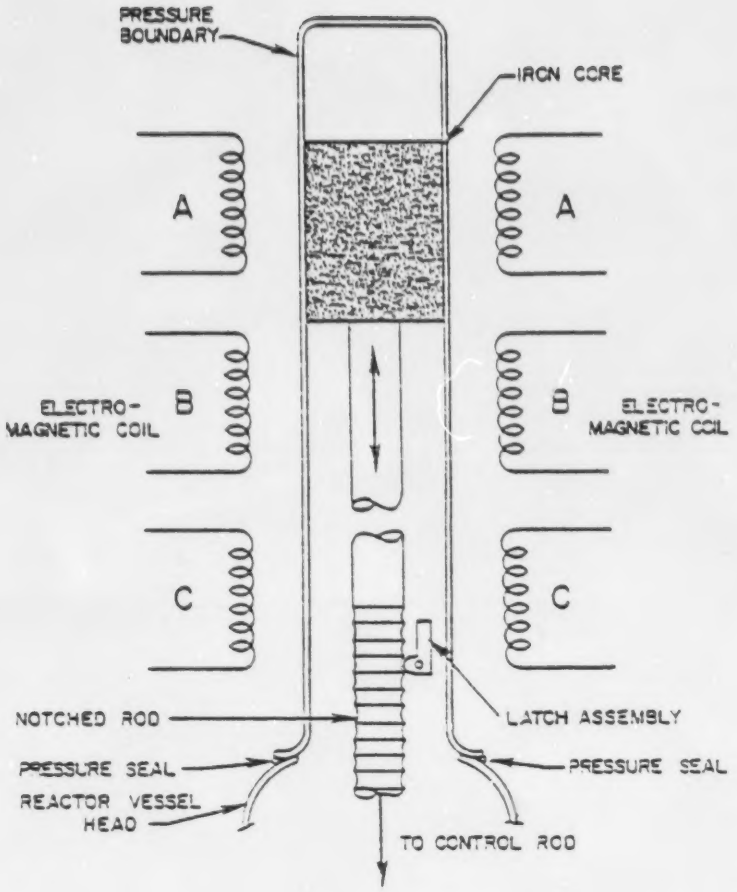

Figure 6-4-12. Magnetic-jack rod-drive mechanism.

A combination magnetic moving circuit and mechanical ratchet.

A magnetic movement and magnetic holding device.

It should be noted that, with both of these mechanisms, a loss of electrical power causes the rod to scram.

PWR ROD-DRIVE MECHANISM

The pressurized rod-drive mechanisms previously discussed, which are basically used on PWR's, are usually mounted on top of a reactor vessel (Figure 6-4-13). The

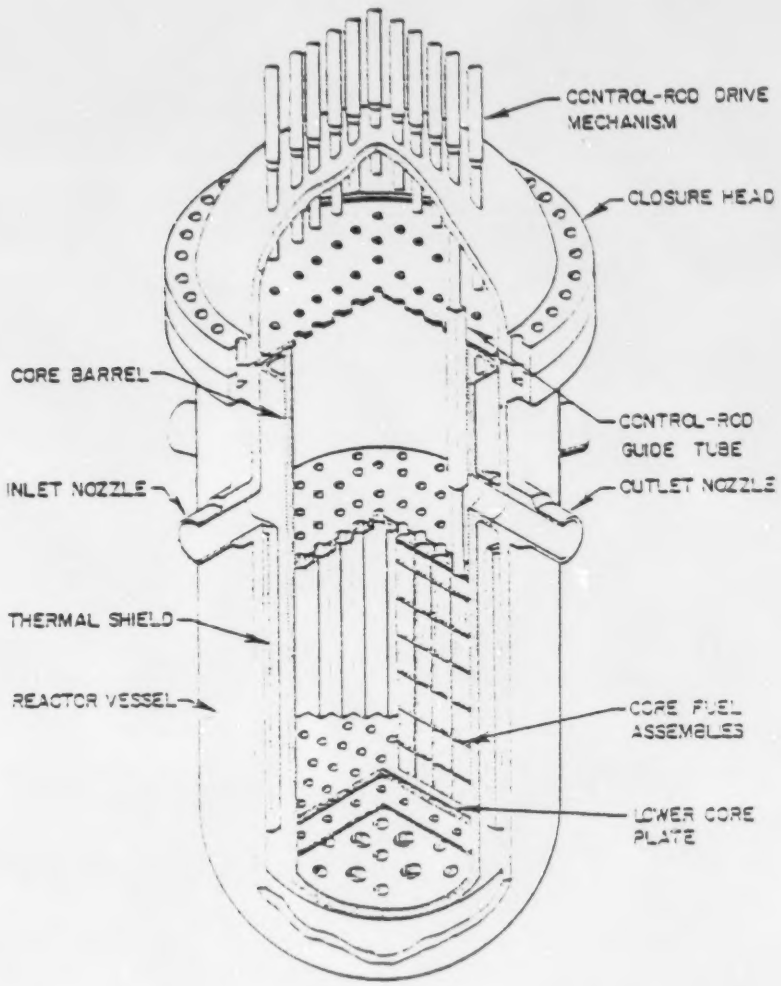

Figure 6-4-13. PWR vessel.

arrangements are simple and straightforward, unlike BWR rod-drive mechanisms.

BWR ROD-DRIVE MECHANISM

Present day BWR's utilize locking-piston control-rod drive mechanisms (Figure 6-4-14), which are bottom-entry,

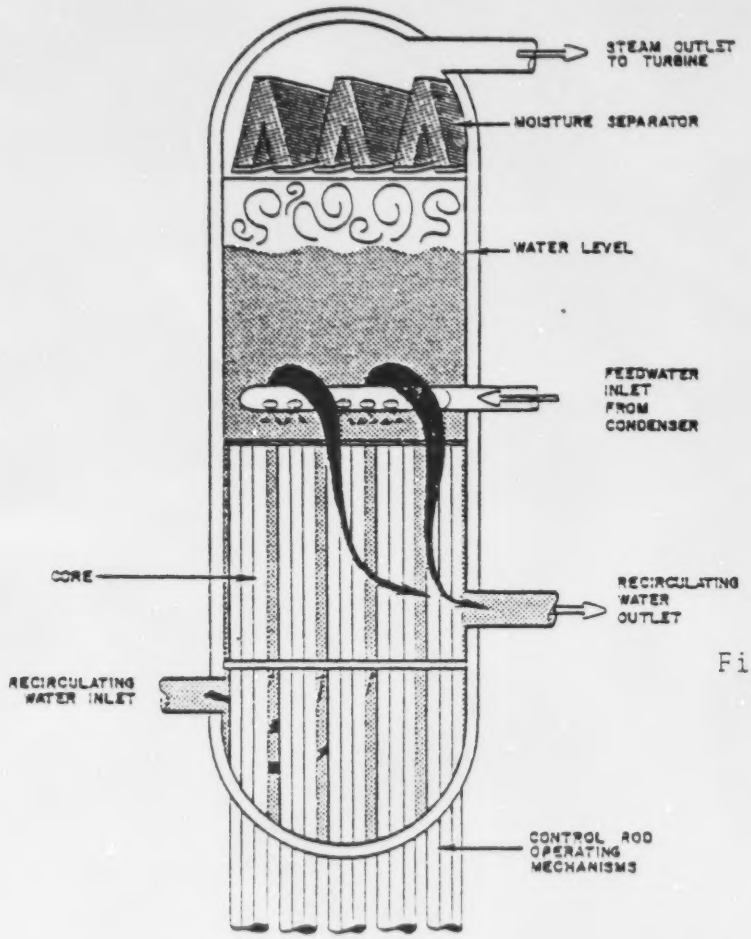

Figure 6-4-14.
BWR vessel.

bottom-mounted hydraulic actuators using reactor feedwater as the hydraulic fluid. Bottom-mounted drives do not interfere with refueling and are operative when the head is removed. Also, they are quite accessible for inspection and servicing, and their location maximizes water in the core, providing a neutron shield to minimize the neutron dose to component parts.

The basic drive system (Figure 6-4-15) starts with

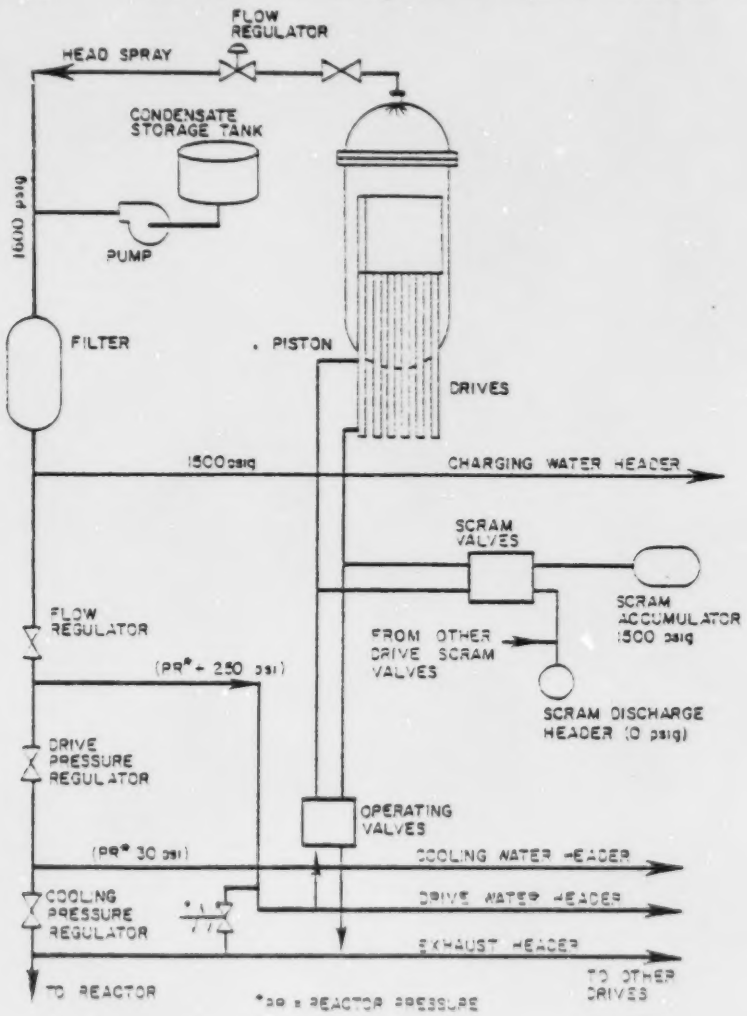

Figure 6-4-15. BWR basic control-rod drive system.

water being taken from the condensate storage tank and pumped to 1600 psig. Pressure control for normal operation (not scram) is obtained by maintaining a constant flow through a series of pressure reducing valves and discharging the flow to the reactor. The first regulator maintains a pressure of 250 psi above reactor pressure (PR) for rod positioning, and the second regulator maintains pressure at 20 psi above PR for drive cooling. Excess water is discharged to the reactor.

Drive insertion is accomplished by opening the two "insert" valves (Figure 6-4-16), which applies reactor pres-

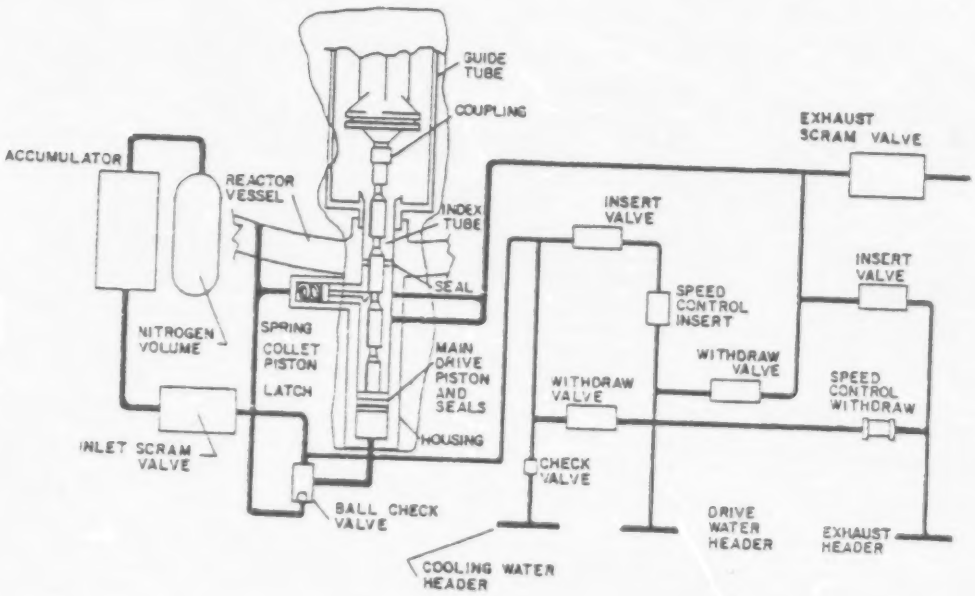

Figure 6-4-16. Locking piston drive system.

sure plus 250 psi to the piston and opens the chamber above the main driving piston to the exhaust header (at reactor pressure). The 250-psi difference acting on the differential area of the piston (approximately four square inches) exerts an upward force of up to 1000 pounds. The rod is inserted because force is greater than friction load (normally less than 100 pounds) plus weight of blade and index tube. The latch is constructed in such a manner that it is cammed open and acts as a ratchet during insertion. The speed with which the drive moves is preset by the pressure drop through the adjustable speed-control valve. During normal motion, this pressure drop accounts for all but about 80 to 90 psi of the operating differential. If drive slows down for any reason, however, full differential is available to cause continued insertion.

By design, drive withdrawal requires a more complex sequence of events. First, the notches in the index tube and the latch mechanism are shaped such that any downward force (such as rod weight) on the index tube locks the latch in place and, therefore, the index tube must be given upward motion before the latch can be unlocked. This motion results from opening the "insert" valves in the manner described in the paragraph above for approximately one second. The "withdrawal" valves are then opened (by sequencing timer mechanism), applying driving pressure above the main piston and opening area below the piston to the exhaust header. (Drive return spring in the latch mechanism plus force of reactor pressure oppose movement of the latch piston.) When this area is opened, the drive is free to move in the "withdraw" direction.

This entire sequence of operation is accomplished automatically by the automatic sequence timer upon initiation

of the "withdraw" signal by the operator.

Water displaced by drive piston flows out through the speed-control valve, determining speed at which the drive moves. Two speed-control valves are used to provide separate insert and withdrawal speed adjustments. Cooling water flow is interrupted by the small check valve during rod movement, but is re-established after the rod is positioned, although none of the structural (metal) members is affected by exposure to the maximum reactor water temperature. Also, the flow of cooling water into the drive minimizes the amount of foreign material that might enter the drive from the reactor.

Drive scram action is as follows: the scram valves open, admitting the pressure in the accumulator (approximately 1500 psig) under the main drive piston and venting the chamber over the piston to the scram discharge header. This header is maintained at atmospheric pressure during normal plant operation. The accumulator pressure produces a large upward force* on the index tube and control rod, giving the rod a high initial acceleration, and providing a large margin of force to overcome friction or any possible binding. Each drive requires about 2.5 gallons of water during the scram stroke. As water is drawn into the drive, accumulator pressure falls below reactor pressure, and the ball check valve (located within drive flange) shifts its position and admits reactor pressure to bottom of piston.

Capacity in the accumulator is sufficient to complete a scram in the required time when the reactor is at atmos-

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* Initial scram force is a maximum of about 6000 pounds under cold reactor conditions and is approximately 3000 pounds when reactor is at operating pressure.

pheric pressure, in which case the ball check valve remains in the position shown. When reactor is at its normal operating pressure, accumulator reserve provides initial scram energy source and, as stored pressure decreases, reactor pressure maintains the large force margin. Without an accumulator, scram force is still over 1000 pounds when reactor is at its operating pressure.

Restoration of the water charge to accumulators following a scram is automatic after scram valves are closed. The automatic flow control reduces flow to the drives while accumulators are recharging, but maintains a minimum flow through the vessel return line to protect the nozzle from thermal shock.

The piston-type scram accumulator associated with each control-rod drive is charged with an inert gas (nitrogen). During plant operation, the gas charge is retained even after repeated drive operations and scrams.

Characteristics of the hydraulic system are designed so that after the initial acceleration (less than 30 milliseconds after start of motion) the desired scram velocity of about five feet per second is achieved. This characteristic provides a high initial insertion rate and a high operating-force margin that cannot be approached by drives utilizing gravity forces for scram. As the drive piston nears the top of its stroke, the piston seals close off the larger passages in the exhaust line and the drive is slowed down. There are eight passages that are progressively closed and provide controlled deceleration.

EXERCISES

1. Given a schematic diagram of a PWR primary coolant loop, trace liquid poison injection system and explain purpose of each component.
2. Explain why a liquid control system gives more uniform power distribution than a solid control system. Is liquid poison concentration higher or lower at beginning of cycle?
3. Why do large power reactors have large excess reactivities at beginning of cycle? How is this compensated for?
4. For four major reactor manufacturers, list 1) control geometry, 2) absorber materials, 3) number of control rods, 4) whether followers are used, 5) type of drive mechanisms and 6) rod lengths.
5. Explain why it would be ideal for control rods to possess each property listed (on page 8 of text).

MATERIALS

1 rack-and-pinion drive mechanism.
1 fixed-screw, movable-nut drive mechanism.
1 fixed-nut, movable-screw drive mechanism.
1 magnetic feedthrough drive mechanism.
1 magnetic-jack drive mechanism.
1 BWR hydraulic drive mechanism (optional).

PROCEDURES

Instructor will demonstrate these drive mechanisms:

Rack-and-pinion (with and without clutches).
Screw-and-nut (two types).
Magnetic feedthrough.
Magnetic jack.
BWR hydraulic (optional).

Students are to sketch each drive mechanism, label major components and describe principles of operation.

Note: Instructor may have students design and build the above mechanisms as class projects.

DATA TABLE

None.

REFERENCE MATERIALS

Lish, Kenneth C. Nuclear Power Plant Systems and Equipment. New York: Industrial Press, 1972.

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1. List and describe, with aid of illustrations, three types of nonsolid control element systems:

2. Briefly describe the most common solid control scheme; give two main disadvantages of this scheme and how each can be compensated for:

3. Sketch four different control-rod geometries; explain which one(s) is most commonly used:

4. Describe effects of using three different types of longitudinal variations in control elements:

5. Given six most commonly used control element materials; give advantages and disadvantages of each:

6. List and describe at least five properties that an ideal control-rod material must possess:

7. Sketch each of the following control-rod drive mechanisms; label major components; describe principles of operation:

Rack-and-pinion.

Screw-and-nut

Fixed-screw, movable nut.

Fixed nut, movable screw.

Magnetic feedthrough.

Magnetic-jack.

BWR hydraulic.

8. List drive mechanisms commonly used with PWR's; with BWR's; explain why:

NUCLEAR TECHNOLOGY

MODULE 6-5 INSTRUMENTATION POWER SUPPLIES. -

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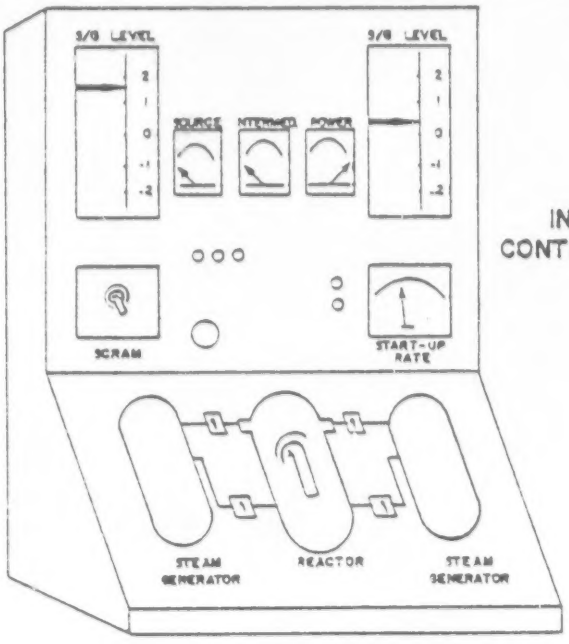

INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

COURSE 6

TERC-SW

TECHNICAL EDUCATION RESEARCH CENTER — SOUTHWEST
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COURSE MODULES

COURSE 6 INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

MODULE 6-1 Neutron Monitoring Systems

MODULE 6-2 Neutron Sensors

MODULE 6-3 Neutron Flux Signal Conditioning

MODULE 6-4 Control-Rod Drives and Indicating Systems

MODULE 6-5 Instrumentation Power Supplies

MODULE 6-6 Installation of Instrumentation Systems

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INTRODUCTION

This module is concerned with two types of power supplies:

High-voltage detector supplies.
Low-voltage supplies for the remainder of the neutron flux signal-conditioning circuitry.

The basic circuitry of nuclear detector and instrumentation power supplies is presented. The student is exposed to detector and instrumentation requirements for power supplies, as well as typical ways of meeting these requirements.

MODULE PREREQUISITES

Student must have completed a basic course in electronics and the prior modules in this Course.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Track operation of a typical power supply by identifying each major subsystem in a schematic diagram and

discuss its use and effect on supply output.

2. From an oscilloscope display, sketch voltage waveforms of each major subsystem of a power supply.
3. By using an actual malfunctioning power supply, diagnose the problem.

POWER SUPPLY GENERAL PARAMETERS

Each of the detectors discussed in previous modules of this Course places various requirements on its power supply. A BF_3 tube, operated in the proportional range, requires around 2000 volts regulated to within 1% or 2% because its constant-counts plateau is only on the order of 300 to 400 volts in width.

A fission counter, on the other hand, usually is operated in a range from 150 to 300 volts, again with around 1% or 2% regulation being acceptable.

Uncompensated ion chamber power-supply requirements are similar to these; however, a compensated ion chamber places some special requirements on its power supply, particularly if its output is used for reactor period circuitry.

An intrinsic capacitance exists between a collector electrode and positive and negative electrode walls. This capacitance, shown diagrammatically (Figure 6-5-1) as C_N

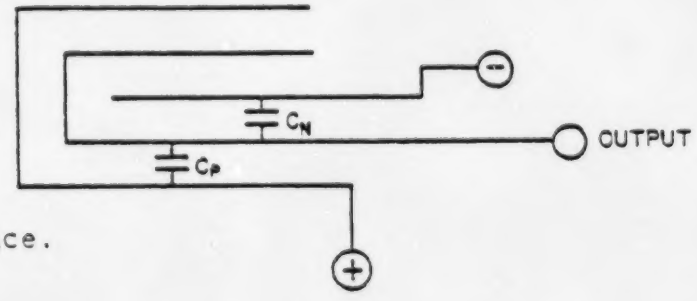


Figure 6-5-1.
Intrinsic capacitance.

and C_p, is typically on the order of 100 pf (10^{-10}f). A voltage rate of change equal to 0.1 volt/second is equivalent to 10^{-11} amps. Typically, the lower limit of a detector's output current range is on the order of 10^{-11} amperes. In this case, a requirement that voltage drift be less than 0.01 volts is acceptable.

An amplifier circuit utilized in neutron flux signal-conditioning circuitry is sensitive to power supply oscillations and drift. For this reason, it requires a well regulated supply capable of maintaining proper terminal voltage over a wide range of current.

POWER SUPPLY SPECIFICATION PARAMETERS

Power supplies are usually specified by two common parameters: 1) percent of regulation and 2) percent of ripple. As will be seen, power supply terminal voltage varies over a range of values as supply current is increased to its maximum rating:

$$\% \text{ regulation} = \frac{\% \text{ load voltage} - \text{full-load voltage}}{\text{full-load voltage}} \times 100.$$

Equation 6-5-1
(Equation = Eq.)

Percent ripple is a measurement of output voltage variation from a true voltage level:

$$\% \text{ ripple} = \frac{\text{RMS ripple voltage}}{\text{full-load d.c. voltage}} \times 100. \qquad \text{Eq. 6-5-2}$$

The root mean square (RMS) value of ripple voltage (Figure 6-5-2) is often difficult to obtain. In practice,

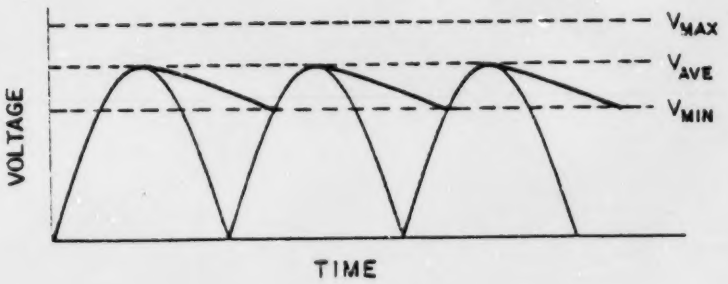


Figure 6-5-2. Full-wave rectifier.

therefore, approximations of peak-to-peak values for ripple voltage are often used in place of RMS values:

$$\% \text{ ripple} \approx \frac{\text{peak-to-peak ripple voltage}}{\text{full-load d.c. voltage}} \times 100 \qquad \text{Eq. 6-5-3}$$

where full-load d.c. voltage = V (average voltage).

PASSIVE POWER SUPPLY FILTERING

In a full-wave rectifier with a capacitor filter (Figure 6-5-3), as supply voltage reaches its peak value, E_s, capacitor C is fully charged. As E_s decreases, and if time constant

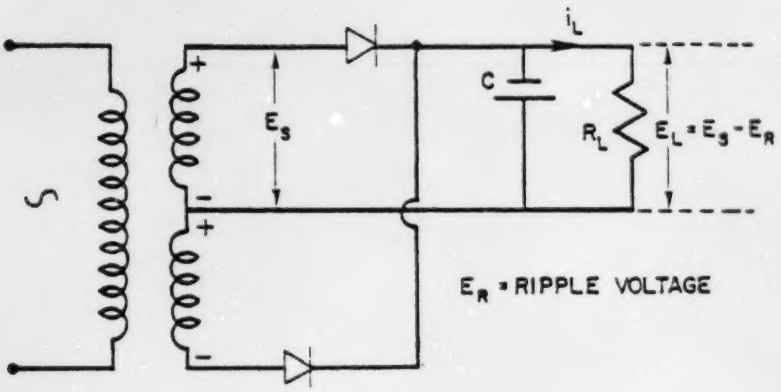


Figure 6-5-3. Full-wave rectifier with capacitor filter.

CR_L is sufficiently long, the diodes are reverse-biased (cut off), and the capacitor begins to discharge through the load resistance. This process continues for approximately $T_s/2$ seconds (where T_s is the supply voltage period), until the next supply voltage peak occurs.

A full-wave rectifier with a capacitator filter provides satisfactory smoothing applications (if load current is limited to a few miliamperes). Charge lost and required capacitance to meet ripple specifications are directly proprotional to the load current. A current-sensitive coil, i_L, may be added (Figure 6-5-4) to extend current range of the filter.

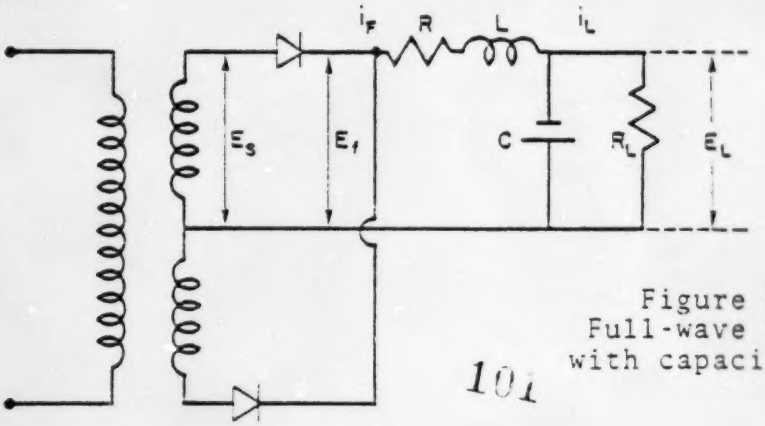


Figure 6-5-4. Full-wave rectifier with capacitor filter.

Current i_F and voltage are composed of a.c. and d.c. components. The d.c. component of bridge voltage E_f is the time-averaged value of the rectified 60-cycle voltage:

$$E_f^{d.c.} = \frac{2E_s}{\pi} = 0.636\ E_s. \qquad \text{Eq. 6-5-4}$$

(A complete frequency analysis by advanced techniques is required to completely specify the a.c. component of E_f.)

The problem with these methods of regulation is that they are strongly influenced by load (presented to power supply). Variation in terminal voltage and power supply performance factors can be excessive from no-load to full-load condition. Active power supply filters provide an adequate solution to this regulation problem.

ACTIVE FILTERS

Zener diodes are among the simplest devices used to maintain constant terminal voltage in a power supply (Figure 6-5-5). A zener diode is designed to function in

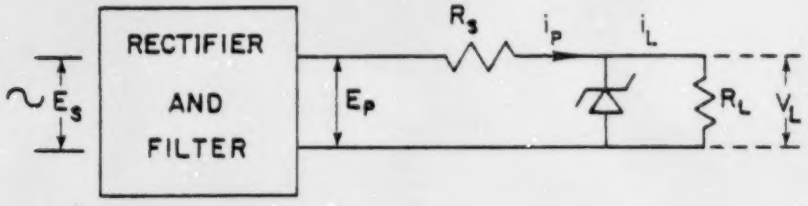


Figure 6-5-5. Typical power supply circuit, including zener diode.

its reverse-biased breakdown region (Figure 6-5-6). Variations in power supply output voltage and current, accomodated by the zener diode, maintain a nearly constant voltage across the load. There is little change in V_L over an extensive range of current, i.e., the zener diode handles almost all the increase in current caused by an increase in

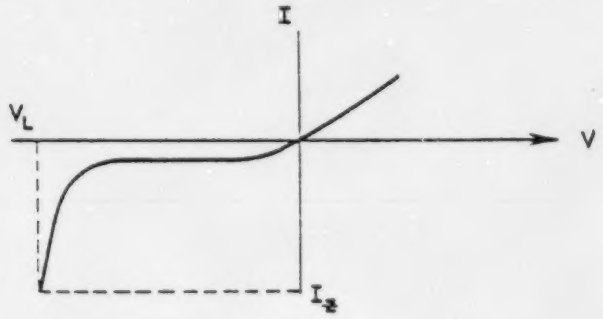


Figure 6-5-6. Zener diode reserve-biased breakdown.

rectified voltage. A lessening of the rectified-voltage level reduces the zener diode current level, allowing the load to take most of the power supply output current i_p. (Note: The circuit is designed so that maximum diode current is less than the maximum rated current of the diode.)

The "pass element" circuit (Figure 6-5-7) emitter fol-

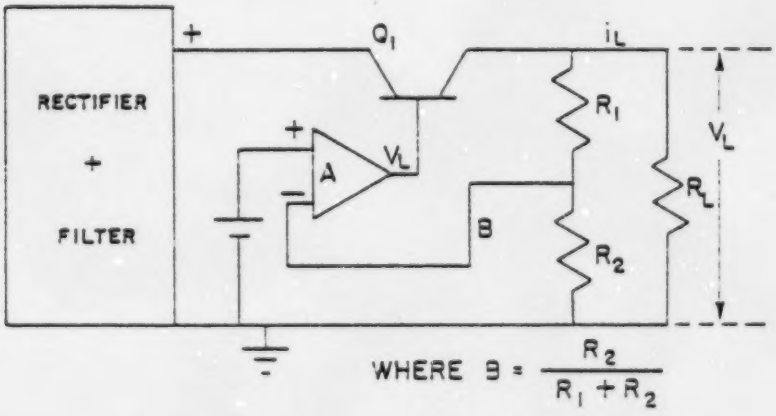


Figure 6-5-7. Series voltage regulator.

lower is operated with a forward gain of approximately 1, which implies $V_L' \approx V_L$. A portion of output voltage V_L is fed back to the differential amplifier, and compared with reference voltage V_R. Any change in V_L caused by power supply ripple, or a change in R_L, results in an inverse change in the forward gain of Q_1, which tends to hold V_L constant.

A functional circuit based on Figure 6-5-7 can be realized in practice (Figure 6-5-8). The zener diode, D_Z, establishes a reference voltage. Consider an increase in out-

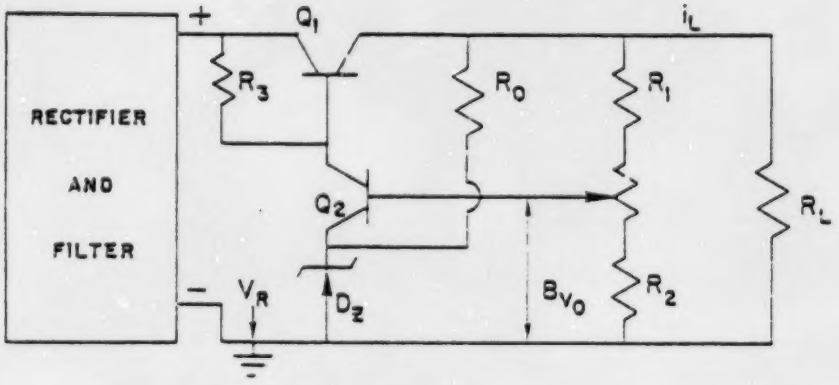


Figure 6-5-8. Functional series voltage regulator.

put voltage V_L; this increase results in an increase in the base-to-emitter voltage of Q_2, which increases Q_2 collector-to-emitter current, reduces the collector voltage of Q and lowers base voltage at Q . Normally, base voltage at Q is slightly greater than emitter voltage. The increase in V_L and decrease in Q collector voltage reduces Q base-to-emitter voltage, reducing Q current gain. This reduction lowers i_L and reduces V_L until the circuit returns to its initial balanced condition. Similarly, a decrease in V_L

increases Q_1 base-to-emitter voltage, increasing the forward gain of Q_1, which results in an increase in V_L until the circuit again balances.

EXERCISES

None.

MATERIALS

1 oscilloscope.
1 functioning series voltage regulator (with basic subsystems shown in Figure 6-5-8).
1 faulty power supply.

PROCEDURES

Use oscilloscope and faulty power supply; diagnose fault.

DATA TABLE

None.

REFERENCE MATERIALS

Angelo, E. J., Jr. Electronic Circuits. New York: McGraw-Hill Book Co., 1964.

McLain, S. and Martins, J. Reactor Handbook, Vol. 4. New York: John Wiley and Sons, 1964.

Millman, J. and Halkias, C. Integrated Electronics. New York: McGraw-Hill Book Co., 1964.

1. Trace operation of power supply shown in Figure 6-5-8; identify each major subsystem:

R_0 =

R_1 =

R_2 =

R_3 =

Q_1 =

Q_2 =

R_L =

i_L =

BV_0 =

D_Z =

V_R =

2. Briefly describe use and effect of each of the major subsystems:

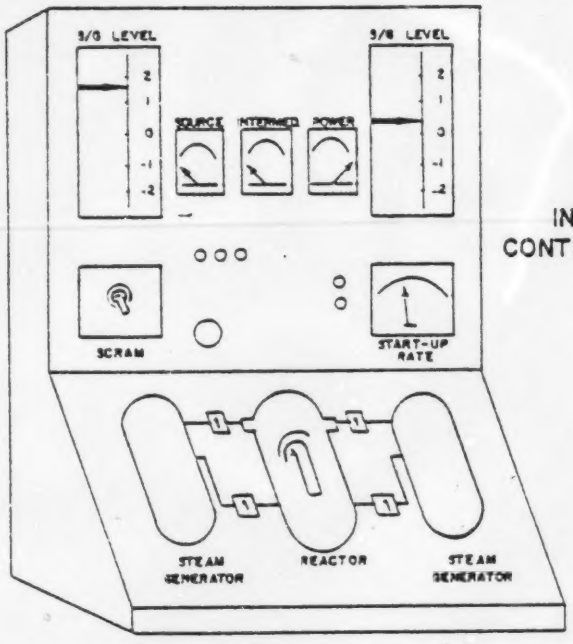
Subsystem	Use	Effect
R_0		
R_1		
R_2		
R_3		
R_L		
Q_1		
Q_2		
i_L		
BV_0		
D_Z		
V_R		

3. Use an oscilloscope; sketch voltage waveforms of each major subsystem:

NUCLEAR TECHNOLOGY

MODULE 6-6 INSTALLATION OF INSTRUMENTATION SYSTEMS. -

JAMES M. RICHARDS, JR.



INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

COURSE 6

TERC-SW

TECHNICAL EDUCATION RESEARCH CENTER — SOUTHWEST
4201 LAKE SHORE DRIVE WACO, TEXAS

COURSE 6 INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

MODULE 6-1 Neutron Monitoring Systems

MODULE 6-2 Neutron Sensors

MODULE 6-3 Neutron Flux Signal Conditioning

MODULE 6-4 Control-Rod Drives and Indicating Systems

MODULE 6-5 Instrumentation Power Supplies

MODULE 6-6 Installation of Instrumentation Systems

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INTRODUCTION

Previous modules in this course have described design and operation of instruments used to monitor nuclear reactors. This module addresses instrumentation in more general terms with respect to instrumentation configurations and installation means within nuclear plants.

This module also describes 1) types of systems used to accumulate and transmit information, 2) installation procedures for these systems, and 3) quality-assurance programs, which ensure that installations are of the highest quality and reliability obtainable.

MODULE PREREQUISITES

The student should have completed all previous modules in this Course.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. List and describe four types of instrument systems; include their relationship to operator.
2. Describe three instrument characteristics controlled by national standards.
3. Describe components of an instrument system; include their inter-relationships.
4. List three classes of instrument panels.
5. Discuss installation steps for an instrument system.
6. Discuss techniques used to install instrumentation systems; state why certain steps/techniques are used.
7. List and describe quality-assurance/quality-control procedures necessary for installation of a nuclear instrumentation system.
8. Perform a sample inspection on an installed instrumentation system.

Nuclear plant instrumentation systems provide information transfer between operating personnel and various process systems. Because a large physical area is covered by a nuclear reactor and its associated process systems, highly reliable monitoring and control devices are needed to minimize the number of operating personnel and maximize each operator's ability to assess plant operating conditions.

Instrumentation systems include a wide variety of functions:

Monitoring of process variables.
Transmitting operator demand functions.
Providing data manipulation.

Many control functions are provided by an instrument system, but various control functions are not considered a part of instrument system. Typically, these functions are two-state controls (switch positions, off/on control, etc.).

In general, instrument systems may be grouped within four categories:

Process/Operator Instrumentation (direct indicating) typified by 1) local indication devices, such as dial thermometers, 2) direct transmitting systems, which provide remote display of variable parameters, and 3) transducers, which modulate basic parameters to provide indications of either intermediate or postulated paramenters.

Operator/Process Instrumentation (open-loop control) provides an analog process response to a variable control device: e.g., an operator places a valve in an intermediate position by adjusting an electronic input to a variable controller.

Process/Process Instrumentation (closed-loop control) controls the process variable in response to a process-sensing instrument: e.g., a flow controller operates a variable displacement control valve in response to a flow transmitter signal. Closed-loop controls are operated within manually preset limits.

Process/Record Instrumentation (data logging) by which process parameters not considered necessary for immediate operator information are displayed on "hard copy" record devices. Hard copy records are available for operator's subsequent review in the form of typewritten logs, punched computer tapes, or pen lines on charts.

INSTRUMENTATION STANDARDS

Because of the complexity of instrumentation systems, national standards have been developed to assist in their design and installation. National Electrical Manufacturers Association (NEMA) standards and Institute of Electrical and Electronic Engineers (IEEE) standards, in document form, typically include:

Output signal ranges: transmitter and transducer outputs are available in industry-wide standard ranges to facilitate input to other instrumentation.

Standardized power supplies: reduced voltage power supplies are available that minimize supply voltage transients and associated instrument errors.

Mounting methods: (for various types of instrumentation) are standardized (as well as overall physical dimensions).

Additionally, enclosure standards have been developed to assist in specifying appropriate physical configurations for various environments.

INSTRUMENT SYSTEM COMPONENTS

Basic components of an instrumentation system (Figure 6-6-1) include:

Transmitters (or local indicators).
Intermediate signal conditioners (transducers).
Interconnecting cables.
Remote display (or control) devices.

In all types of transmitter installations (Figure 6-6-2), process connections are made to provide sensor isolation and removal under operating conditions.

Signal transducers (when used) may be situated adjacent to a primary transmitter and on a local instrument panel, or on a remote indicating/control panel. They are used for signal calibration, scale conversion, algebraic functions and so on.

A typical example of signal conditioning might be instrumentation that provides plant thermal output indications. Volume flow rate of plant cooling water is algebraically combined with differential temperature (of cooling water entering and leaving plant). Electronics for this indicator are set to

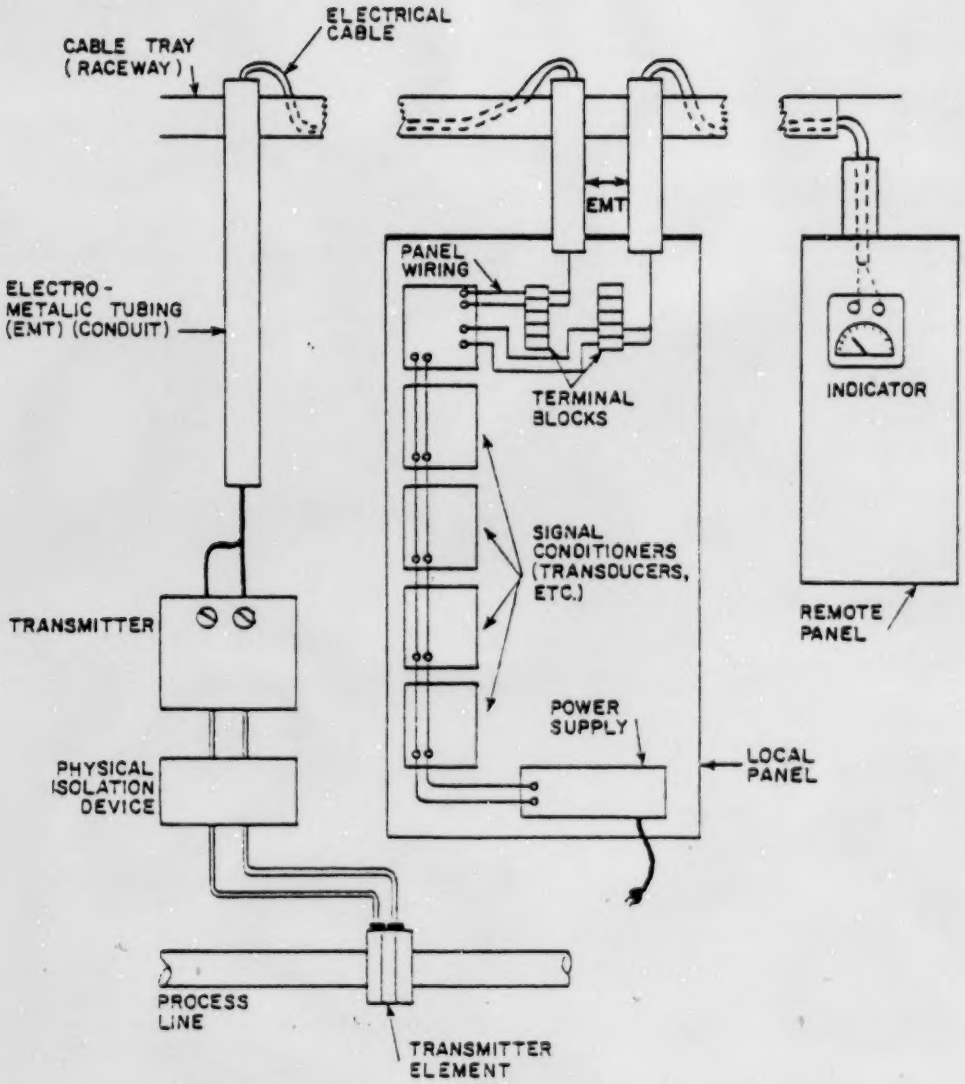

Figure 6-6-1. Instrument system components.

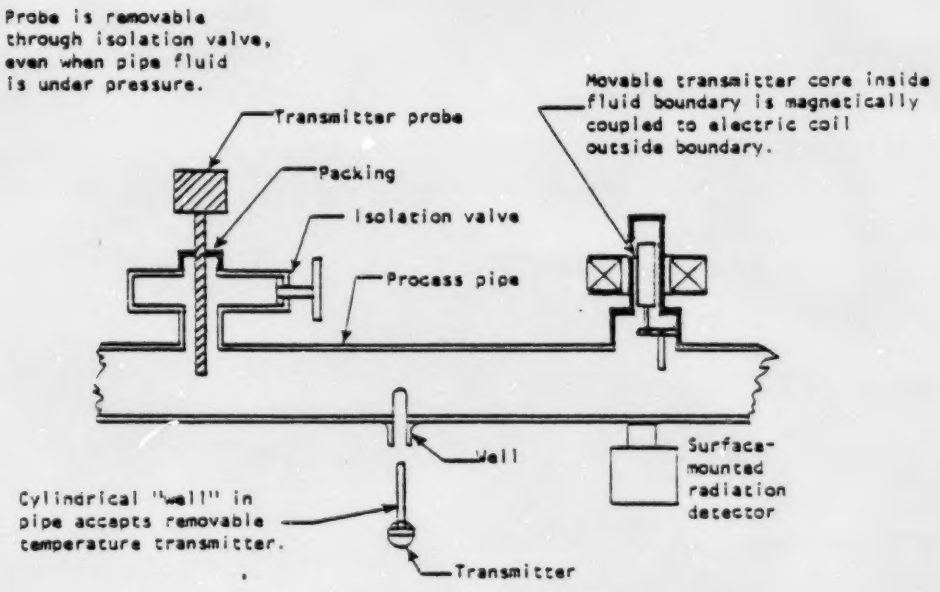
Probe is removable through isolation valve, even when pipe fluid is under pressure.
Transmitter probe
Packing
Isolation valve
Process pipe
Movable transmitter core inside fluid boundary is magnetically coupled to electric coil outside boundary.
Wall
Surface-mounted radiation detector
Cylindrical "well" in pipe accepts removable temperature transmitter.
Transmitter

Figure 6-6-2. Four typical transmitter mounting and protection methods.

solve the following:

$$Q = KF\ (T_{out} - T_{in}) \qquad \text{Equation 6-6-1 (Equation = Eq.)}$$

where K is a scale converter, which includes all constants in the formula, and is variable to provide for calibration.

Solution of the equation by inputs from the three variable sensors allows indication of plant thermal output - a postulated (versus monitored) parameter.

Interconnection between transmitters, local panels, and remote indication devices is normally provided by electrical cables. It should be noted that pneumatic (variable air pressure) signal transmission also may be used.

Cables require their own subsystem for protection and support. This subsystem, called the "raceway," consists of metallic trays and tubing (Figure 6-6-1).

Instrument panels, provided for a number of physical and electrical considerations, may be classified according to construction, type of access, and methods provided for instrument mounting (Figure 6-6-3).

The instrument enclosure is usually a welded sheet-metal box, which may range in size from a small outlet box to a "walk-through" control panel. The enclosure box normally is selected for custom design instrument layout.

A second type of panel construction, an instrument rack, consists of vertical support members pre-drilled to accept standard "rack type" instruments. Rack construction is used for standardized, high-density instrument installation.

Panels are also classified as to the type of maintenance access provided:

Front only.
Front and rear.
Tunnel.

The front-only configuration provides indication, control and termination facilities, all on one face of the instrument panel. Only low-density mounting is accomplished on this type of panel.

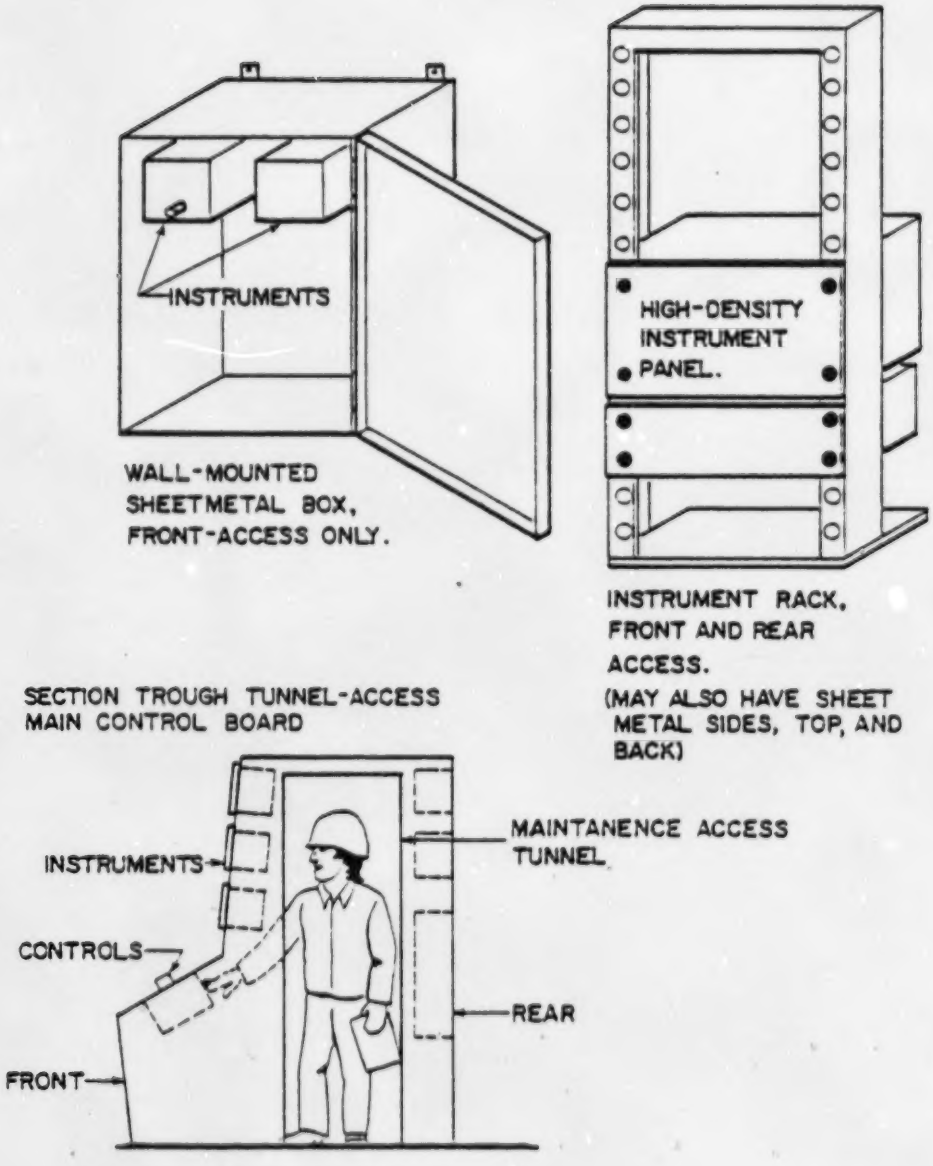

Figure 6-6-3. Instrument panel construction.

Front and rear panels are suitable for higher density mounting because they allow one face (the front) for indication and control and another (the rear) for cable termination.

Tunnel panels are large enough to allow personnel access into the panel for installation, calibration and maintenance. This arrangement allows front and rear panels to be used for indication and control. This type of panel is usually selected for the main control boards.

Selecting the appropriate type of panel should be based on the need for concentrated display and control (in the case of an operator interface) and on maintenance and accessibility requirements.

INSTALLATION STEPS

New components to be installed in instrumentation systems should be thoroughly inspected upon receipt to verify the following:

Equipment was not damaged in shipment.
Equipment is actually as ordered.
Proper installation instructions and operating adjustments are described on attached literature.

Proper preparation, at this point, may easily prevent system damage and wasted time during equipment installation. In addition to ensuring that all components are ready for installation, system(s) to receive new equipment should be inspected to verify the following:

Mounting devices (for new equipment) are installed.

Piping has been modified to accomodate new transmitters (if required).

Plant operating conditions are such that personnel hazards, as well as hazards to new equipment, have been minimized.

The first step in installing an instrument system is to erect or otherwise implace the required instrument racks or panels.

The second installation step is to provide metal raceway(s) between the various instrument locations. Where extensive EMT or pipe is utilized, additional metal boxes are provided at intervals to facilitate subsequent cable installation. The last few feet of raceway to be routed to a transmitter normally is flexible tube. This section limits transmission of stress and vibration from a transmitter to the raceway.

When all raceway and instrument racks (or panels) are installed, a continuous metal containment should exist for all cables associated with the instrument system.

The next step is to install interconnecting cable. When laying new cable, the color coded cables should only be laid in portions of the raceway identified for their use. For pulling new cables through metallic tubes or pipes, a "fishtape" (string or ribbon) is normally provided throughout the length of each tube or pipe. To pull the cable, first a lightweight rope or line (normally 1/4" diameter manila rope) is pulled into the tubing by the fishtape. When the line is sticking out at both ends of the conduit, instrumentation cable can be pulled through by the line. When all cable has been suitably installed within the raceway system, a continuity test must be made to verify that no cable damage was sustained during installation.

The next item to be installed is the instrument transmitter. Caution should be used to ensure that the process system (which may be under high temperature or high pressure) is isolated and that proper installation techniques are followed.

After the transmitter has been installed, interconnecting cables are terminated. At this point, the transmitter is monitoring the process system, and electrical continuity has been provided to a local panel where additional signal conditioning is performed.

Local signal conditioning panels, normally completely prewired, house various transducers and indicators to be used for instrument calibration and conditioning. Process transmitter cables are terminated on "interface terminal blocks" provided within the local panel.

In addition to incoming cables from the transistors, outgoing cables to remote indication devices also should be terminated at interface terminal blocks. Following installation of all incoming and outgoing cables, instrument functional continuity should be provided from the transmitter, through the local panel transducers, to the end of the cable at the remote indication panel.

Installation of devices, such as indicators, recorders and controllers, at the remote panel normally is accomplished by flush-mounted devices. This mounting technique allows high-density display and control functions (required at the instrument/operator interface). Cable terminations to these devices, located at the rear of the instrument, accept cables from the local panel.

Power supplies normally are located at the local panel; however, they may be located at either the transmitters or remote indicators. Power supply inputs normally are derived

from standard distribution equipment, such as 120-volt a.c. wall plug. Power supply outputs normally are wired into input/output terminal blocks.

INSTALLATION TECHNIQUES

Because instrument transmitters are situated at various process locations within the plant, transmitters are subjected to damage that may occur during maintenance and operation of process systems. Additionally, the processes to be monitored may contain high-temperature or high-pressure fluids or caustic chemicals. All of these hazards can be protected against by appropriate transmitter installation.

Transmitters can be protected from high-temperature process systems by thermal insulating mechanical linkages. Also, in an instance in which sensors cannot withstand high-pressures, a "well" may be used as a pressure boundary, or a movable-core pressure transmitter may be used (Figure 6-6-2). To protect a transmitter from vibrating components, such as a motor or high-energy fluid system, a flexible connection can be used, allowing the transmitter to be mounted on a separate, rigid frame.

A high-strength cast metal casing is often an option that can be specified for an instrument transmitter. Instrumentation that does not have this type of protection may be enclosed within a cast metal case for physical protection. A variation is an insulated case, which offers instrument protection from high ambient temperatures.

During installation, considerable caution must be exer-

cised to provide adequate separation of adjacent runs of power supply cables and instrument cables. The magnetic fields surrounding the power cables may induce "noise" into the cables, resulting in signal errors.

Additional protection against induced electrical noise is provided by conductive shields around the signal conductors. Shield continuity must be maintained throughout the cable run, and shield ground connections should be provided as often as possible.

Additional noise reduction is provided by containing instrumentation cables within metallic pipes, tubes and tray systems (raceways). In addition to the ability to reduce noise, a conduit or tray provides physical protection for instrumentation cables.

For those instrument systems which are highly critical, a second (redundant) instrument system monitoring the same parameter may be provided.

Although numerous types of terminating devices are available for the wide variety of electrical conductors, the most common mode of terminating instrument cables is with crimp-type connectors. These connectors are divided into two configurations:

"Spade" connectors, which have open ends to allow insertion around terminating screws (without removing screw).

"Ring" connector, which does not have this feature (requires removal of terminating screw).

In selecting the type of connecting lug to be used, it should be noted that spade connectors facilitate frequent changes in termination connections and shorten installation time; however, spade connectors are subject to working loose (due to component vibration). Ring connectors, on the

other hand, provide positive termination.

Attachment of either of these termination connectors to the cable is accomplished by means of an integral tube on the connector. The tubes are in various sizes specified to match the diameter of the wire in American wire gage (AWG) sizes. The connector is attached to the conductor by use of a "plier-type" crimp tool. The crimp tool squeezes the tube-shaped portion of the connector into a solid contact with the conductor.

Panel interconnecting wiring is accomplished by the use of single conductor insulated wires routed into wire bundles, called harnesses, and terminated as discussed above. When installing panel wiring, care should be used to provide wires that are long enough to not put any strain on the termination points. Wires should be trained into neat bundles, securely attached to the panel structure.

When installing a differential pressure transmitter, both the high-pressure and low-pressure isolation valves should be closed and the cross-over valve (equalizer) should be opened. The transmitter is attached to the mounting device (provided near the process tap location) and metallic tubing is used to interconnect the device with the three-valve manifold. When a differential pressure device has been installed and pipe fittings are secure, the high- and low-pressure isolation valves may be opened and all tubing and fittings checked for evidence of leaks or malfunctions.

The procedure for installing an insertion-type probe is simple. With the isolation gate valve firmly closed, insert probe through the upper packing nut. Then, snuggly tighten packing nut against body of probe; slowly open the isolation valve. When the isolation valve has been fully opened, the probe may be inserted into the process pipe.

Care should be taken to ensure that if alignment arrows are provided on the probe, as in the case of turbine flow meter, they should be pointing in the direction of fluid flow. After fully inserting the probe, the packing nut is further tightened to prevent probe motion.

INSPECTION

Instrument system inspection can be accomplished by any one of several methods, which include:

Physical inspections.
Try tests.
Logic continuity.
Train actuation.
Calibration testing.

Inspection may be performed to satisfy any one of a number of requirements, such as equipment preventative maintenance, regulatory-required pre-operational tests, and quality control.

Physical inspection is normally included with other types of instrumentation system testing. Items to be checked for include cracked or broken components, loose cables, moisture buildup, corrosion, and arcing or pitting of electrical components.

Instrument testing is ideally performed by changing parameters, monitored by an instrument system and verifying that the final device (indicator or control) responds within specified accuracy. In a simple instrument system, this type of ideal testing may be performed. An example might be

to monitor an electronic indicator and a mechanical indicator, both of which are responding to the same parameter. Since the mechanical indicator is intrinsically accurate, proper performance of the electronic instrument can be verified. Should the electronic instrument fail to accurately indicate the process parameter throughout the range of indication, it should be calibrated.

Because it is seldom practical to apply this ideal test, an alternate method of varying an instrument signal calls for the use of a predetermined "dummy" signal. For this method to be effective, the exact relationship between the process variable and the transmitter output must be known. This relationship is provided by an output characteristic curve (available for each electronic transmitter and transducer).

When specific instrumentation is to be calibrated, the manufacturer's calibration procedure should take precedence.

Safety system actuation instrumentation is the instrument system which initiates an automatic control response to perform a safety function for a nuclear related process system. Testing of the actuation instrumentation is accomplished by one of the following methods:

Logic continuity test.
"Try" test.
Full-train actuation test.

In full-train actuation testing, input sensors for one of the two redundant actuation systems are placed in their "tripped" mode. If this action results in the proper safety devices (pumps, valves, etc.) being actuated, the entire train of instrumentation is considered to be operating satisfactorily.

In a "try" test, key components are prevented from oper-

ating to allow other portions of the system to be tested without resulting in final component operation.

In a continuity test, low voltage or pulse test signals are used to verify the capability of electronic components to initiate process device actuation. (Because full voltage actuation signal is not applied, the final component does not operate.)

Due to the complexity of nuclear reactor safety actuation systems, an automatic tester is often used. This tester is preprogrammed to perform actuation system tests in rapid sequence.

REQUIREMENTS FOR INSPECTION

Although there are many reasons for performing periodic tests and inspections of an instrument system, these reasons can usually be grouped into two general categories:

Preventative/repair maintenance.
Regulatory-required inspections.

Preventative maintenance frequency is determined by the component history and by consumable supply usage. In general, the frequency of this maintenance is directly preportional to the complexity of the component. Normally, simple components operate for much longer periods than complex components, with relatively little inspection required. The consumption rate of consumables, such as chart paper and chemicals, is normally constant and, therefore, the maintenance time frame for this consideration can be accurately established. Additionally, inspection and testing may be prompted by abnormal occurances,

which result from instrument system abnormalities or failures - separate instrumentation initiates appropriate alarm(s).

Regulatory inspections, specified by either state or Federal regulatory agencies, are described in each nuclear plant's operating license. Regulatory requirements classified as pre-operational tests must be performed during plant start-up and power escalation. These tests establish instrument and safety actuation system availabilities prior to proceeding beyond certain specified nuclear reactor power levels. (Additional regulatory requirements, to demonstrate operability of automatic safety actuation systems, call for periodic testing during plant operation.)

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) is a system of procedures, inspections and documentations that defines and assures compliance with specified minimum quality and reliability characteristics for nuclear reactor safety systems. Quality Control (QC) is that portion of the QA program that monitors implementation of QA requirements.

One QA goal is to provide documented material traceability for procurement of materials, fabrication of subcomponents and assembly of major components. This documentation also contains records of any inspections or tests performed during equipment manufacture. This system of checks and documentation is partially implemented by each manufacturer's QA program, which has been approved by the purchaser prior to material fabrication.

In addition to routine manufacturing inspections, the QA program includes "hold points," which allow a user to in-

spect manufacturing processes at various critical points. The final hold point is normally identified to occur immediately prior to material shipment. During this hold-point inspection, a user inspector determines overall suitability of 1) the equipment being supplied and 2) the documentation being compiled under the manufacturer's QA procedures.

Upon receipt at a nuclear plant, safety-related material goes through a second phase of quality assurance, implemented by the plant's QA program. This program begins with a receipt inspection. During this inspection, the material is checked for damage as well as for completeness of QA documentation supplied with it. When this inspection is completed, the material is placed in segregated storage to prevent mixing of safety-related and nonsafety-related equipment.

The equipment remains in QA-controlled storage until it is required for installation in the plant. Plant installation of a QA component is controlled by a QC program (discussed below). Following installation, additional documentation verifying that the proper component was installed in the proper location is placed in the quality-assurance record to provide the last link in a continuous train of documentation, from initial manufacture of the component to final installation within the nuclear plant system.

The quality-control program generally applies to the methods of ensuring that the QA requirements have been met and specifically addresses control of the installation procedure at the nuclear plant. In implementing the QC procedure, the installer must verify that all proper receipt and manufacturer's documentation has been provided. Installer may then proceed with a pre-installation inspection. Specific requirements for this inspection are determined for each device and include provisions for calibration checks, physical dimen-

sion checks and functional testing. In any event, the goal is to verify specified operating characteristics of the component.

When all QA/QC checks and procedures have been completed, installation may proceed. The installer of this safety related material must be an approved installer with specifically documented background and training. In addition, at least one independent check of this installation must be performed by either 1) a second, equally qualified, installer or 2) a member of the quality-control organization. These independent checks also must be documented in accordance with QA procedures.

Following installation, the component/system is tested to verify its proper operation in accordance with system design specifications. Should a component be determined to be incapable of performing its intended safety related function, it is considered to be a "nonconforming component." Nonconforming items are identified by a controlled tag. The component and any system it affects cannot be considered operational until the nonconformance is resolved. Resolution is accomplished by replacement of defective equipment, or by system redesign if equipment is not defective.

Dependent upon the complexity and critical nature of the installation, the entire QA record may have to be reviewed by engineering or plant operations personnel prior to placing the modified or installed subsystem or component in service. Optionally, special testing may be required to prove design (or equipment) acceptability. When special review or testing requirements have been met, the system may be placed in service.

1. An operator must control a mass of water in a holding tank; tank volume is to be monitored by a differential pressure transmitter; volume is to be corrected to mass by monitoring tank temperature; tank volume is to be automatically controlled by a variable position drain valve (assume a continuous supply to the tank):
   - What basic components must be installed to inform the operator of tank mass?
   - What additional components must be installed for the control valve to automatically maintain mass at a value predetermined by the operator?
   - What provision may be made to allow both the differential pressure transmitter and the temperature transmitter to be replaced while a high-pressure condition exists in the tank?
   - Assume that the operating temperature in a tank is in excess of the specified maximum for the pressure transmitter; describe a method of thermally isolating the transmitter.
   - What technique may be used to ensure that tank-borne vibrations are not transferred to an instrument system?
2. Contrast construction of an instrument panel (used for high-density instrument mounting) with one that provides a custom-design operator interface.
3. Which type of instrument panel access configuration(s) provides the lowest density of instrument installation?
4. Describe components, and discuss multiple purposes, of a raceway.

5. Describe implementation of a QA/QC program for an instrument system; include activities to which this program applies.

MATERIALS

1 container of water and ice (at 32°F).
1 container of boiling water.
1 resistance temperature detector (RTD) with resistance-versus-temperature characteristics curve.
1 resistance - current converter (R/I), 4-20 ma output, 115 vac power.
1 milliamp meter to accept 0-25 ma.
1 decade resistance bridge.
Terminal lugs, lug compression tool and cable.
1 laboratory thermometer (dial or mercury column) that indicates 0°F to 212°F.

INSTALLING DIRECT-INDICATING INSTRUMENT LOOP

1. Locate water containers to represent variable process to be monitored; mount thermometer and RTD in a cold water bucket; at a second location, establish a "local panel" by mounting the R/I transducer near an electric outlet; at a third location, establish the meter as a "remote panel."
2. Install interconnecting cables between various locations; use crimp type terminal lugs for all terminations; verify correct installation with instructor.
3. Energize instrument loop by plugging in transducer; adjust zero potentiometer until meter indicates 4 milliamps.
4. Transfer RTD to boiling water; wait a few minutes for meter reading to stabilize; adjust transducer span potentiometer until meter indicates 20 milliamps.
5. Repeat steps 3 and 4 until transfer of RTD between containers requires no further calibration.

INSPECTING DIRECT-INDICATING INSTRUMENT LOOP

1. With thermometer and RTD in ice water, verify thermometer reading of 32 degrees and meter reading of 4 ma.
2. Increase water temperature to approximately room temperature; verify that thermometer and meter readings agree within accumulative instrument loop accuracy. To

determine the correct meter reading, establish a linear scale between 4 and 20 ma on meter (in units of 10°, between 32 and 212°F).

3. Disconnect RTD cable at RTD; reconnect it to (decade resistance) bridge. (Note: De-energize transducer during this step.)
4. With transducer re-energized, establish associated resistance for each of the following temperatures (the correct resistance for each temperature is determined from the resistance-versus-temperature characteristic curve; dummy signals should result in a meter indication as listed plus or minus accumulative transducer and meter accuracy):

Temperature:	32°F	77°F	122°F	167°F	212°F
Meter:	4 ma	8 ma	12 ma	16 ma	20 ma

5. Verify results of 1) direct comparison and 2) resistance characteristics tests with instructor.

DATA TABLE

None.

REFERENCE MATERIALS

Considine, D. M., ed. Handbook of Applied Instrumentation. New York: McGraw-Hill, 1964.

Gallagher, J.M. Jr., Committee Chairman IEEE. IEEE Std. 279 1971, Criteria for Protection Systems for Nuclear Power Generating Stations. New York: Institute of Electrical and Electronics Engineers, 1971.

Harrer, J.M. and Beckerley, J.G. Nuclear Power Reactor Instrumentation Systems Handbook, Vol. 1. Springfield, VA: USAEC, Office of Information, Technical Information Center, 1974.

1. List four types of instrument systems (as described in this module):

2. Describe three instrument characteristics controlled by standards:

3. Describe components of a typical, complete instrumentation system:

4. List three types (or classes) of instrument panels:

5. Differentiate between quality control and quality assurance as these terms apply to nuclear power reactor instrumentation:

NUCLEAR TECHNOLOGY

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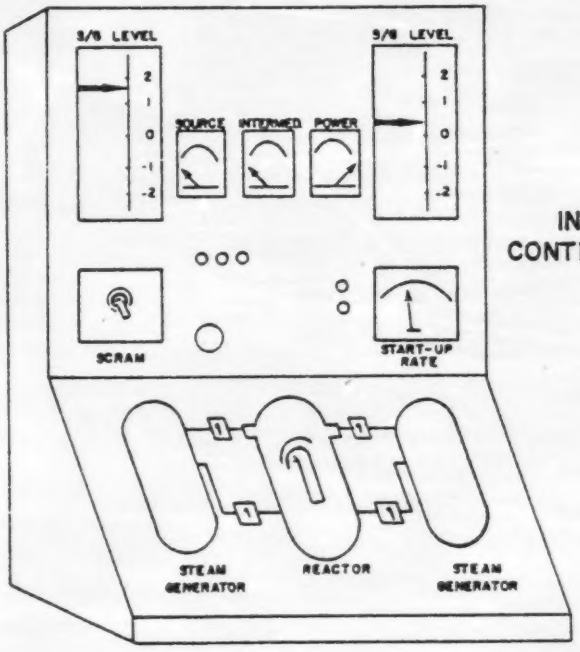

INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS

COURSE 6

TERC-SW

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NUCLEAR TECHNOLOGY SERIES

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for

COURSE 6, INSTRUMENTATION AND CONTROL OF REACTORS AND PLANT SYSTEMS (SIX MODULES)

NOTE: Each module in this Course is numbered separately, and the page numbers begin with page 1 in each module. Therefore, this Index lists for each entry the module number (underlined), followed by a comma and the page number. Figures and tables are listed by their numbers, followed by the module and page number in parentheses. A Master Index is available in a separate volume. This general index merges all index entries from the 35 Nuclear Courses. It is a valuable research tool, with which the student or researcher can locate all the references to any subject within the 35 Courses.

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